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RESEARCH MEMORANDUM

STATISTICAL SURVEY OF ICING DATA MEASURED ON SCHEDULED AIRLINE FLIGHTS OVER THE UNITED STATES AND CANADA FROM NOVEMBER 1951 TO JUNE 1952

By Porter J. Perkins

Lewis Flight Propulsion Laboratory
Cleveland, Ohio

NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS
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STATISTICAL SURVEY OF ICING DATA MEASURED ON SCHEDULED AIRLINE FLIGHTS OVER THE UNITED STATES AND CANADA FROM NOVEMBER 1951 TO JUNE 1952

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SUMMARY

A statistical survey and a preliminary analysis are made of icing data collected from scheduled flights over the United States and Canada from November 1951 to June 1952 by airline aircraft equipped with NACA pressure-type icing-rate meters. This interim report presents information obtained from a continuing program sponsored by the NACA with the cooperation of the airlines.

An analysis of over 600 icing encounters logged by three airlines operating in the United States, one operating in Canada and one operating up the coast to Alaska, is presented. The icing conditions encountered provided relative frequencies of many icing-cloud variables, such as horizontal extent, vertical thickness, temperatures, icing rate, liquid-water content, and total ice accumulation.

Liquid-water contents were higher than data from earlier research flights in layer-type clouds but slightly lower than previous data from cumulus clouds. Broken-cloud conditions, indicated by intermittent icing, accounted for nearly one-half of all the icing encounters. About 90 percent of the encounters did not exceed a distance of 120 miles, and continuous icing did not exceed 50 miles for 90 percent of the unbroken conditions. Icing cloud thicknesses measured during climbs and descents were less than 4500 feet for 90 percent of the vertical cloud traverses.

INTRODUCTION

Meteorological data obtained from NACA icing research flights in supercooled clouds have provided information for the design of present ice-protection systems (ref. 1). These data were received from a relatively small number of flights within the United States. As a result of specialized flight planning involving selected weather conditions, flight paths, and cruising altitudes, the information provided may not have been representative of conditions encountered by aircraft on routine schedules following conventional flight procedures. Additional knowledge of the icing problem including the extent, frequency, and severity of icing conditions experienced by scheduled airlines over world-wide air routes is required by aircraft designers and by aircraft operators in prescribing flight control procedures.

A program to obtain these more extensive icing-cloud data is being conducted by the NACA Lewis laboratory in cooperation with several major airlines and the United States Air Force. Several types of aircraft are equipped with NACA pressure-type icing-rate meters specifically developed for measuring icing encountered during scheduled operations. A preliminary report has been issued (ref. 2) which described the initial phase of this program over only one transcontinental air route in the United States from January through May, 1951. The program later was expanded to cover many domestic and overseas air routes and off-airway areas.

This interim report presents a preliminary analysis of data collected by three airlines (United, Eastern, and Northeast) operating in the United States from November 1951 to June 1952. Data for the same period have also been included from Trans-Canada Air Lines operating across southern Canada and from Pan American World Airways flying the Pacific Coast route to Alaska. A limited number of aircraft from each airline were equipped with the icing-rate meters which recorded continuous values of altitude, airspeed, and icing rate during icing conditions. Much of the data was limited to film records only. The cooperation of the airlines in obtaining these data is gratefully acknowledged.

A detailed study of the frequency of icing conditions with respect to total time over the various routes was not possible because the total flight times of the instrumented aircraft were unknown. An inspection of flight logs will be made later to find the flight time on airways and at various altitudes.

APPARATUS AND PROCEDURE

Icing-Rate Meter

The icing-rate meter installed on the airline aircraft was a pressure-actuating type developed by the NACA Lewis laboratory specifically for collecting statistical icing data. The meter (described in ref. 3) consists of three units, the ice-sensing probe, the film recorder, and the control unit (fig. 1).

The principle of operation of the meter is explained in figure 2, which shows an ice-sensing probe of 0.1-inch diameter containing small total-pressure holes mounted in the airstream and connected to a differential pressure switch. The total pressure from the probe is balanced against an ice-free total-pressure system (the conventional pitot pressure system in the aircraft). When the holes in the ice-sensing probe start to plug as ice builds up on the probe, the pressure in the probe side of the pressure switch decreases. This is accomplished by allowing the air in the system to flow out through a small orifice connected to a static-pressure source. At a given value of differential pressure, the switch energizes an electric heater which de-ices the ice-plugged holes, thereby restoring the pressure balance. The time required to actuate the switch, or the heat-off period of this cyclic process, is inversely related to the rate of ice accumulation on the probe and is used as a measure of the icing rate. The calibration of the ice-sensing probe for rate of ice accretion in inches per hour is discussed in the appendix.

Recording of Data

Icing rate, indicated airspeed, and pressure altitude were recorded on photographic film contained in a replaceable drum. The film recorder started automatically at the beginning of each icing condition and shut off automatically 15 minutes after the end of icing for each encounter. The 15-minute record after icing had terminated provided approximately a minimum of 50-miles separation between icing periods when icing clouds were encountered more than once during the same flight.

A special data sheet requesting supplemental information from the flight crews was supplied by the NACA to correlate with the recorded data. The data sheet (shown in fig. 3) includes such items as time, date, location, and effects on aircraft performance.

A typical film record of icing encountered during a routine airline flight is shown in figure 4. Airspeed and altitude are recorded as continuous traces, and the icing-rate indications are shown as broken horizontal lines at the bottom of the film varying in length according to the duration of the heat-off period. The length of each broken line is converted to time and then to icing rate by using the icing-research-tunnel calibration discussed in the appendix. Correlation of the film data with the flight crew observations when available provided detailed information for each icing encounter.

Installation on Aircraft

The icing-rate meters were installed on five different types of aircraft (DC-3, DC-4, Convair 240, Constellation, and North Star). A typical installation of the ice-sensing probe mounted on a DC-4 is shown in figure 5. The installations were usually on or near the top of the fuselage and as far forward as possible. Flight tests on each type aircraft were made to determine whether the air-flow characteristics and total pressure at the probe locations were the same as those measured by the conventional pitot tube.

The film recorder was mounted in the aircraft at a convenient location for replacing the film drums. The airspeed and altitude capsules in the recorder were connected to the conventional total- and static-pressure systems in the aircraft. The indicating lights on the control unit, or in some cases on a separate panel in the cockpit, alerted the flight crew to record the information on the supplemental data sheet when the film recorder operated in an icing condition. An indication of the rate of icing on the ice-sensing probe was supplied to the crew by a flashing light paralleled with the cyclic de-icing system of the probe. 3017

ANALYSIS OF DATA

An icing encounter was defined as a period of continuous or intermittent icing where periods of nonicing did not exceed 15 minutes. Periods within an icing encounter during which ice accumulation was continuous, as indicated by at least one operating cycle of the meter during a 1-minute period, are defined in this analysis as icing incidents. Separating periods of continuous icing from periods of nonicing gave a limited estimate of the discontinuous nature of the icing clouds.

Individual icing encounters were separated on the film by simultaneous breaks in all the continuous traces. Each encounter was then associated with the corresponding entries on the data sheet. The encounter was marked off on the film in 1-minute intervals, and the icing-rate, altitude, and airspeed traces were each averaged and computed as one value for each 1-minute period. The pressure altitude was measured to an accuracy of ±100 feet using NACA standard atmosphere. Since the indicated airspeed fluctuated considerably, particularly in areas of turbulence, the average values were calculated within about ±3 miles per hour.

The simultaneous measurements of altitude and rate of icing on the film made possible an analysis of the vertical extent or thickness of icing-cloud layers encountered during climbing and descending. These cloud-thickness measurements may not in some cases be fully correct because of the impossibility of determining from the records whether the aircraft traversed the full extent of the layer. The aircraft may have entered or emerged from the cloud at some point between the top and bottom. Also, errors may be caused in some cases by long horizontal distances resulting from slow rates of climb or descent. Also, in many cases the vertical extent of multiple layers may not have been completely surveyed because cruising altitudes are often assigned between cloud layers.

The measurements of icing rate and airspeed were used to calculate values of liquid-water content of the icing clouds. In this report liquid-water content w in grams per cubic meter was computed from the relation

$$w = 15.8\ (R/V)(\rho/E)$$

where

R icing rate, in./hr

V true airspeed, mph

ρ density of ice

3017

E collection efficiency of sensing probe

Both the density of ice ρ on the probe and the droplet collection efficiency E of the probe were assumed constant with ρ/E as unity for all conditions. Some simultaneous measurements of liquid-water content using the icing-rate meter and rotating multicylinders have been made during icing research flights. This limited comparison showed that the meter measurements are generally higher than those from the cylinders, particularly in conditions where liquid-water content fluctuated considerably and produced high peak values. The two methods agreed within 10 percent in icing conditions that produced a steady rate of icing with water contents under 0.5 g/cu m. Collection efficiency variations resulting from changes in droplet size and limited accuracy of the icing-rate measurements probably contribute to the limited agreement of the two measuring methods.

Droplet-size data were not obtained in this program because of measurement difficulties, thereby preventing a complete evaluation of the severity of the icing encounters. The probable severity of the icing conditions can be estimated, however, by relating the extent of the icing encounters, the liquid-water content, and the temperature data which are measured in this survey to previous icing measurements which included droplet sizes. The frequency distribution of droplet sizes have been obtained by instrumented research flights by the NACA and other agencies and are reported in reference 4.

RESULTS AND DISCUSSION

The approximately 600 icing encounters analyzed in this report were logged during the period from November 1951 through June 1952. These encounters gave almost 10 times the amount of data reported in the preliminary survey of reference 2 because of the greater amount of flying time accumulated during the latter period. The data are assembled and summarized in tables I and II. Table I contains all icing-rate meter measurements which could be associated with the corresponding flight crew observations. Table II contains all icing-rate meter measurements which could not be associated with flight crew observations either because of questionable correlation of the individual icing encounters or the absence of any flight observations when the meters were operating. Flight crew observations which could not be correlated with any icing-rate meter records were included in analyses of the frequency of occurrence of icing with respect to altitudes and icing-cloud temperatures.

Because of the manner in which the data were collected, the icing data presented herein should not be used to evaluate the full range of meteorological variables that may be associated with icing clouds. The airline aircraft collecting the data followed conventional flight procedures established to reduce the potential hazard of icing encounters. Known icing conditions were probably avoided wherever possible. If icing was encountered which was considered hazardous or in any way hampered the conduct of the flight, airway clearances were obtained, if possible, to climb or descend out of the icing condition. As a result, such conditions would not be fully surveyed since the maximum horizontal extent would not be known and possibly the maximum severity would not be encountered. In some cases, however, severe conditions cannot be avoided because of traffic restrictions or altitude limitations. The occurrence of such circumstances is undoubtedly very infrequent; therefore, the full extent and severity that may exist in icing conditions will probably not be measured during scheduled airline operations until a large amount of data is assembled. The amount of information presented herein is probably sufficient to give representative icing values for airline operation over many of the areas covered.

The number and types of instrumented aircraft with the corresponding number of icing encounters over the various air routes are listed in the following table. Although five types of airline aircraft were instrumented, most of the meters were installed on types which limited a predominant part of the data to relatively low altitudes.

Airline	Number of aircraft with meters installed	Type of aircraft	Routes covered	Number of icing encounters
United	6	DC-4	Transcontinental and Pacific Coast U.S.	319
Eastern	1	Constellation 749	Eastern U.S.	83
Northeast	2	DC-3 and Convair 240	Northeast U.S.	58
Trans-Canada	1	North Star (DC-4)	Transcontinental (Southern Canada)	79
Pan American	1	DC-4	Pacific Coast between U.S. and Alaska	83
Totals	11	5 types	6 areas	622

Air routes covered by survey. - All the icing data were collected along the air routes flown by the five airlines as outlined in figure 6. The United States was covered by a transcontinental air route from New York to San Francisco, by East Coast routes from Miami to northern Maine, and by a West Coast route from Los Angeles to Seattle. A limited amount of data was obtained from a transcontinental route across southern Canada and from a Pacific Coast route to Alaska from Seattle. The air route across the United States, which was also surveyed the previous season
3017 (ref. 2), supplied data from the Great Lakes area and over the Central Rocky Mountains.

The frequency of occurrence of icing with respect to particular areas or routes could not be determined at the time of this analysis because the amount of total flying time with meter-equipped aircraft over any particular area or route, for the period of the survey, was not known. Since the instrumented aircraft were not generally confined to any one route, the data received from a particular aircraft did not represent the frequency of icing for a given route.

Horizontal Extent of Icing Clouds

Prolonged periods in icing conditions even at low rates of accumulation can produce adverse effects on aircraft performance. Certain unprotected aircraft components which can tolerate small accumulations of ice are hampered by large accretions resulting from extensive icing periods. Hence, the horizontal extent of an icing encounter is of particular significance in evaluating icing conditions. The extent of icing during airline operations is usually measured during straight-line flight, although some encounters may be prolonged because of holding or following some other traffic-control procedure within an icing area. The distance between scheduled stops influences the extent of icing measured by some airlines, particularly those with short routes.

A study of the film records showed that almost one-half the prolonged icing encounters contain intermittent periods during which ice does not form indicating broken icing-cloud formations. Conditions of continuous ice accretion over appreciable distances were rather infrequent and usually were associated with severe icing conditions. In cases of prolonged nonicing periods, more than one icing encounter was logged during the flight since, as discussed previously, the meter stopped after a period of nonicing exceeding 15 minutes.

The horizontal extent of icing encounters is tabulated in tables I and II. A cumulative frequency curve plotted from these values (fig. 7) shows that about 10 percent of the encounters extended 120 miles or more and that the greatest distance in an icing encounter was 430 miles. Over 400 separate encounters from all the air routes surveyed during the season are included in this plot. The data include the encounters recorded during climb and descent as well as at cruising altitudes and, therefore, define the extent of icing encounters as experienced during routine airline operating procedures.

The number of icing incidents (periods of continuous ice accretion) within any encounter is tabulated in tables I and II. Over one-half the encounters were single icing incidents (continuous during entire encounter). Only a very small percentage of the encounters contained four or more icing incidents as shown on the graph in figure 8. The maximum number of icing incidents per encounter was obtained from the Pacific Coast route to Alaska where 10 incidents were recorded over a distance of 147 miles in one case and over a distance of 213 miles in another.

The longest icing incident within each encounter is also tabulated in tables I and II. The maximum extent of continuous icing measured was 124 miles, whereas 90 percent of the longest incidents within each encounter were less than 50 miles. These data are plotted as a cumulative frequency curve in figure 9.

The existence of nonicing periods within an encounter shows that continuous icing protection may not be needed during an entire encounter. In many cases, the extent of icing in discontinuous clouds is less than one-half the total extent of the encounter. The lengths of each individual icing incident within each encounter were added together and tabulated as total horizontal distance in icing for each encounter (tables I and II). These data, plotted as a cumulative frequency curve in figure 10, show that 90 percent of the combined icing incidents extended less than 70 miles whereas 90 percent of the full encounters (including nonicing periods) extended less than 120 miles (fig. 7).

Vertical Extent of Icing Clouds

About 40 percent of the encounters were recorded during either climb or descent, thus providing a substantial quantity of data for evaluation of the thickness of icing cloud layers. Possible errors in the interpretation of these data were discussed in the ANALAYSIS OF DATA section. Depending on the operation of the meter, the data were grouped for single or multiple cloud layers. A multiple-layer cloud system was interpreted from the film record when a period of nonicing existed for at least 1 minute while the aircraft was changing altitude. This method does not establish the actual existence of multiple layers but rather separates intermittent conditions from continuous periods of ice accretion during climb or descent.

The vertical extent of icing clouds obtained from these data is plotted in figure 11. The maximum multiple-cloud thickness measured was

10,800 feet compared with only 4000 feet measured during the early part of the statistical program (ref. 2). The 10,800-foot descent (12,800 to 2000 feet over the East Coast U. S.) appeared to be composed of three layers of icing clouds in which icing was measured during 44 percent of the descent. The maximum thickness of single layers measured 5500 feet. The cloud thicknesses for all single and multiple layers flown through did not exceed 4500 feet for 90 percent of the climbs and descents. It is of interest to note that about two-thirds of the data providing cloud thickness measurements were obtained during descent and only about one-third during climb. This indicates that, operationally, icing can be more readily avoided during climb, probably because preflight briefing permits a choice of flight path which would in many cases avoid flight through a cloud layer.

3017

Altitude Range of Survey

The airline aircraft collecting the icing data operated over a range of altitude, determined by the type of aircraft, the distance between stops, and the type of terrain over which the flights were conducted. The amount of flight time at various altitudes could not be obtained for the present data and, therefore, the frequency of occurrence of icing with respect to altitude could not be determined. Icing was encountered at altitudes ranging from 1500 to 22,000 feet, whereas the most frequent cruising altitude was 10,000 feet. Because of the small amount of time at higher altitudes, only 5 percent of the icing was encountered at altitudes over 15,000 feet. United Air Lines' flights across the United States and along the West Coast encountered icing predominantly between 5000 and 8000 feet and also between 11,000 and 14,000 feet. Most of Eastern Air Lines' icing data were obtained above 12,000 feet, whereas Northeast Airlines' icing encounters were all obtained below 8000 feet. The Pacific Coast route to Alaska provided icing data at altitudes between 8000 and 13,000 feet.

Temperature of Icing Clouds

The temperature of icing clouds is a prime factor in establishing the amount of heat required for ice prevention or removal in thermal protection systems. The temperature data from this survey are included to add to the published research information (ref. 1) on temperatures of icing clouds. In evaluating the data it should be realized that the conventional aircraft temperature indicator from which the present data were obtained has limited accuracy, particularly in icing clouds. The accuracy of the temperature observation was indicated by the fact that when the frequency of the temperature values was tabulated in 1° C increments the readings peaked at values of 0°, -5°, -10°, and -15° C. The scale of the temperature indicator on most aircraft can be read conveniently only to the nearest 5° C increment, and the values between are approximations.

In calculating the true cloud temperatures from the indicated values, a correction for the kinetic temperature rise in saturated air as a function of airspeed and altitude was applied. A recovery factor of 85 percent for the probe was used based on a flight calibration in dry air of an airline temperature installation. A cumulative frequency curve of the corrected data (table I and other flight crew observations) plotted in figure 12 shows that 90 percent of the temperature observations were above -15° C (+5° F) and that the lowest temperature measured in icing clouds was -27° C (-17° F), which is about equivalent to the lowest temperature previously reported (ref. 1). Figure 12 includes 380 temperature observations from all the air routes. Temperatures obtained across southern Canada and from the Pacific Coast route to Alaska were generally lower than those from the more southern latitudes within the same altitude range.

3017

Icing cloud temperatures as a function of pressure altitude are shown in figure 13. In this plot, the average temperatures were computed for each 1000-foot increment of altitude. The wide spread of temperatures for the altitude range covered by the present data is outlined by the shaded area on the figure. For data obtained during climbing and descending, the temperature readings were assumed to be taken at the altitude where icing was first encountered. A rather consistent drop in the average temperatures with increasing altitude is noted, although there was considerable scatter because of the few observations available at altitudes greater than 15,000 feet. Temperatures from previous research data (ref. 1) also plotted in figure 13 show rather good agreement with the present data below 12,000 feet, but are over 6° C lower at altitudes greater than 12,000 feet. The large differences, particularly at higher altitudes, may be attributed to climatic conditions. Most of the data at altitudes above 12,000 feet were obtained from southeastern United States, whereas a large part below 8000 feet were obtained from northeastern United States. Most of the temperatures from the middle altitudes were measured over the central route across the United States.

Icing-Rate Measurements

The intensity of the icing encounters is defined in this report as the rate of ice accumulation on the icing-rate meter probe. The icing rate was also used to calculate the approximate liquid-water content of the icing clouds. Not all the icing-rate values indicated by the meters can be considered reliable, however, because incomplete freezing or run-off effects were experienced by the probe at cloud temperatures above -11° C. Unfortunately, about 60 percent of the icing-rate data were without corresponding temperature observations and therefore could not be evaluated as being within or outside the reliable range of operation of the probe.

The icing-rate data with associated temperature observations were used to determine the intensity of the encounters. The range of icing rates considered reliable is shown in figure 14 as a function of cloud temperature (discussed in the appendix). This curve shows, for example, that at -6° C (21° F) icing rates up to 5 inches per hour are within the calibration accuracy, but beyond this rate run-off occurs and the data become unreliable. To determine the frequency of occurrence of reliable icing rates as well as those beyond the range of the meter, the data were plotted on a cumulative frequency basis with respect to total time in icing conditions. As explained in the section ANALYSIS OF DATA, the average icing rate was computed for each 1-minute period. This gave approximately 1400 minutes of icing-rate measurements with known cloud temperatures. Figure 15 is a plot of these data grouped according to temperature intervals and considered on a cumulative basis using icing rates equal to or exceeding 1 inch per hour. The temperature grouping allows extrapolations of the icing-rate data beyond the reliable limits. The extrapolations are based on the slope of the curve for the low temperatures which is well defined within the reliable limits. These data can be represented by a straight line on semilog paper. The solid lines extend to the limits of reliable measurements, whereas the dashed lines are extrapolations beyond these limits. Figure 15 indicates that the frequency of given icing rates increases with temperature. This greater frequency results from the greater amount of flying time in icing at the higher temperatures (80 percent of the encounters were above -11° C, fig. 12). The fact that all the lines have the same slope would indicate that there is no dependence of icing rate on cloud temperatures; this may not be quite true for all icing conditions.

Liquid-Water-Content Calculations

Average values of liquid-water content for each 1-minute increment of icing were computed from the corresponding icing-rate values. The results were considered reliable or unreliable as established by the icing-rate data and are plotted in figure 16 for the same temperature intervals as used for icing rates. The solid lines are within the reliable range and the dashed lines represent extrapolations beyond the run-off limits. The greater frequency of higher water contents associated with high temperatures is also evident in this figure. In the temperature interval from -2° to -4° C, about 10 percent of all the data exceeded 0.5 gram per cubic meter; less than 6 percent of all the data exceeded this value at temperatures below -10° C. An extrapolation of the data in the temperature interval from -2° to -4° C shows that 1.0 gram per cubic meter or greater exists for only 2 minutes of every 100 minutes in icing.

A frequency distribution of liquid-water content for all temperatures can be obtained by totaling the reliable and extrapolated frequencies of figure 16. The data in the temperature intervals of figure 16 are combined into the solid line shown in figure 17. Only liquid-water contents greater than 0.1 gram per cubic meter were considered. This figure shows, for example, that the liquid-water content is greater than 1.0 gram per cubic meter for 7 minutes out of every 100 minutes in icing conditions. The total data obtained from the meters including those in the unreliable range are also plotted on this figure. These data indicate that the meters gave somewhat higher values in the unreliable range at liquid-water contents up to about 0.9 gram per cubic meter and then dropped off rapidly as the intercepted water ran off the ice-sensing probe. This comparison indicates that all the measurements (reliable and unreliable) treated as a group are within +15 percent of the probable values up to 1.0 gram per cubic meter.

The water contents measured during airline operation were slightly lower than previously published data from rotating multicylinders taken in cumulus clouds but are considerably higher than similar measurements taken in layer-type clouds (refs. 5 to 8). These comparisons are also plotted on figure 17. Whereas 1 percent of the liquid-water contents of the present data probably exceeded 1.6 grams per cubic meter, the same amount from the earlier data exceeded only 0.7 gram per cubic meter in layer-type clouds. A distinction between cloud types was not possible from the airline observations, although it would be reasonable to assume that most of the records came from layer-type clouds, considering operational procedures, time of the year, and the areas over which the data were taken. The duration of the encounters would further indicate a predominance of data from layer-type clouds. The difference of measuring methods used to obtain these data and those previously published may be responsible for the differences in the data results. The icing-rate meter data are continuous for an entire icing condition and give an average for 1-minute intervals, whereas the multicylinder method only sampled the clouds at certain times and gave an average value over intervals of from 3 to 5 minutes. Also, as pointed out in the previous section ANALYSIS OF DATA the meter indicated higher liquid-water contents than those simultaneously measured with multicylinders in nonuniform icing clouds.

The relation of average liquid-water content to the horizontal extent of icing clouds in an encounter (neglecting nonicing periods) was studied using all the data regardless of the reliability of the measurements. For average liquid-water contents up to 0.7 gram per cubic meter, no particular variation with the extent of icing clouds was evident within distances of about 80 miles. At distances greater than 80 miles, however, average liquid-water content decreased with increasing extent and only 0.3 gram per cubic meter or less existed in distances exceeding 160 miles. The greatest extent of icing clouds measuring above 0.7 gram per cubic meter was 90 miles, and 90 percent of these higher liquid-water contents were in icing clouds extending less than 50 miles.

The icing-rate records indicated considerable variation of liquid-water content accompanying many of the intermittent icing conditions. Average values of icing rate for complete encounters, excluding periods of nonicing which exceeded 1 minute, are tabulated in tables I and II. The average liquid-water content was determined for the longest continuous incident selected from the intermittent conditions in each encounter. These values, also tabulated in tables I and II, are in some cases about 0.2 gram per cubic meter higher than the average for the entire encounter.

Total Ice Accumulation

Liquid-water content and extent of the icing clouds determines the total thickness of ice collected on aircraft components excluding collection-efficiency effects. The total ice thickness is defined as the thickness calculated to accumulate on the sensing probe if it was not de-iced periodically. This can be considered as the largest thickness that any component collects because of the high collection efficiency of the probe. This value is considered to partially measure the severity of an icing condition and is used as a basis for comparison of the statistical data.

An ice thickness that would hypothetically collect on the sensing probe was obtained by totaling the 1-minute periods of icing rate (in./min) measured by the probe during each encounter. The ice thickness was computed for each encounter and is tabulated in tables I and II. A cumulative frequency curve of these values using all the data collected from the meters is plotted in figure 18. This plot shows that about 93 percent of the data are from icing encounters where 2 inches or less of ice would have accumulated on the probe. Conditions yielding up to this amount of ice were called "trace to light icing" by the flight crews, depending upon the cloud temperature and the type of aircraft. Cloud temperature can influence the type of ice formation with equivalent total accretions, creating more adverse conditions (mushroom-type ice) at higher temperatures. Hypothetical ice accumulations greater than 2 inches (7 percent of the encounters) were generally called "moderate icing" by the flight crews. Moderate icing caused losses of airspeed up to 25 miles per hour or required an increase in engine power. The maximum accretion calculated was 6 inches of ice, which was collected over a distance of 151 miles in one case and 158 miles in another case.

A close agreement is shown in figure 18 between the limited quantity of preliminary data obtained during 1950 and 1951 (ref. 2) and the more extensive data collected during 1951 and 1952. The information of this report is almost 10 times the volume of the earlier data. The similarity of data from the two seasons may be explained by the fact that 55 percent of the data of this report were obtained from similar transcontinental DC-4 operations from which all the previous data were obtained.

SUMMARY OF RESULTS

This report summarizes the statistical icing data collected from scheduled airline flights over United States and Canadian air routes from November 1951 to June 1952. The following significant information was provided:

(1) Almost one-half of over 600 separate icing encounters logged by the airline aircraft were intermittent icing conditions where several nonicing periods during an encounter indicated broken-cloud conditions.

(2) About 10 percent of the encounters exceeded 120 miles in horizontal extent, with one encounter reaching a distance of 430 miles. Distances in which icing was continuous, however, did not exceed 124 miles, and 90 percent of these unbroken conditions extended less than 50 miles. These measurements were influenced by the distance between scheduled stops and by other flight procedures which varied among the airlines collecting data.

(3) The vertical extent of icing-cloud layers measured during routine climbs and descents gave maximum cloud thicknesses of 10,800 feet for multiple layers and 5500 feet for single layers. About 90 percent of all the vertical cloud traverses were less than 4500 feet.

(4) Almost 90 percent of the temperatures observed in icing were above -15° C (+5° F), and the lowest temperature observed was -27° C (-17° F).

(5) Liquid-water contents computed from icing-rate measurements exceeded 1.0 gram per cubic meter for 7 minutes out of every 100 minutes in icing conditions. The total frequency distribution of water contents at all temperatures was obtained by extrapolation of the data into the unreliable range of the icing-rate meter. These data are lower than previously published information obtained in cumulus clouds but considerably higher than earlier data taken in layer-type clouds. For horizontal distances exceeding 160 miles, liquid-water contents averaged 0.3 gram per cubic meter or less.

(6) Total ice accumulation, defined as the thickness of the ice calculated to collect on the ice-sensing probe if continuous icing was permitted, was computed to be 2 inches or less for 93 percent of the encounters. The maximum accumulation was 6 inches of ice calculated for two encounters extending about 150 miles.

Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
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3017

APPENDIX - CALIBRATION OF ICE-SENSING PROBE

The rate of icing indicated by the ice-sensing probe can be expressed by the relation

$$R = \left(\frac{T}{P}\right) \times 60$$

where

R icing rate, in./hr

T ice thickness, in.

P icing period, or heat-off time, required to accumulate ice to thickness T, min

The icing period was determined by the ice thickness required to plug the total-pressure holes (0.016-in. diam) in the ice-sensing element (0.1-in. diam) to the point where the differential-pressure switch would be actuated (differential pressure equal to 8 in. of water). The ice accretions on the probe were viewed through an optical enlarging system in the Icing Research Tunnel of NACA Lewis laboratory. These observations showed that the required ice thickness (normally about 0.020 in. on the leading edge) varied with air velocity, air temperature, and rate of icing on the probe. The possible effects of droplet size and altitude were not investigated.

A calibration was made using the magnifying system to measure the ice thickness and a stop watch to measure the icing period. An accuracy within ±10 percent of the indicated icing rate resulted from the limited accuracy of these measurements at the higher icing rates. Since the icing period increases with decreasing icing rate, better accuracy was possible at the lower rates. An icing rate of 12 inches per hour (icing period of about 0.1 min) was considered the readable limit of the instrument, and values exceeding this amount are noted in the data tables as 12+ inches per hour.

Further studies were made in the Icing Research Tunnel to determine the effect of the heat of fusion on the ice accumulating on the probe. Some of the supercooled water impinging on the probe could be seen running back and failing to freeze to the ice surface when the surface temperature was apparently elevated to near the freezing point by the heat released as the impinging water froze on the surface. The conditions for incomplete freezing (run-off) depend upon the ambient air temperature, rate of impingement, air velocity, and altitude. The limits of air temperature and icing rate beyond which run-off occurred were determined visually and are shown in figure 14. Although the ice-sensing probe continues to operate above these limits, the indications are erratic and cannot be considered reliable. Since air velocity and altitude had little effect over the range covered, the run-off limit is shown in figure 14 as a function of only icing rate and air temperature. In the range of conditions in which run-off occurs, the data obtained are useful in defining the horizontal and vertical extent of icing clouds, the frequency of occurrence of icing, and an approximation of the icing severity.

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3017

TABLE I. - MEASUREMENTS AND CORRELATED OBSERVATIONS OF ICING CONDITIONS ENCOUNTERED DURING ROUTINE AIRLINE OPERATIONS FROM NOVEMBER 1951 THROUGH JUNE 1952

(a) Transcontinental and Pacific Coast (U.S.) routes

Pressure altitude,[a] ft	Horizontal extent of encounter, mi	Number of icing incidents for encounter	Total horizontal icing, mi	Average icing rate for all icing incidents, in./hr	Average liquid-water content for all icing incidents, g/cu m	Maximum continuous icing incident within encounter: Average icing rate, in./hr	Average liquid-water content, g/cu m	Horizontal extent, mi	Calculated total ice accumulation, in.	Average true airspeed, mph	Corrected air temperature, °C	Date	Time (local)	Location of encounter	Flight observations and comments
4,100	7	1	7	1.2	0.1	1.2	0.1	7	0.1	208	-6	1/3/52	0616 PST	Salem, Oreg. to Williams, Calif.	Clear rime ice - light intensity
5,000	60	2	52	4.3	.3	5.7	.5	34	1.0	206	-5	1/3/52	0535 PST	Salem, Oreg. to Williams, Calif.	Clear rime ice - light intensity
6,100	8	1	7	3.8	.3	3.8	.3	5	.2	220	-6	1/3/52	0636 PST	Salem, Oreg. to Williams, Calif.	Clear rime ice - light intensity
3,600/2,700	20	1	20	1.7	.2	1.7	.2	20	.3	184	-4	1/3/52	0855 PST	Salem, Oreg. to Williams, Calif.	Clear rime ice - light intensity
3,000/8,000	88	4	55	3.4	.5	5.8	.3	32	.8	212	-7	1/7/52	1526 PST	Richmond, Calif. to Williams, Calif.	Occasional rime in tops of cumulus
10,500	10	1	10	2.9	.2	2.9	.2	10	.2	208	-2	1/8/52	1020 PST	Between Cottage Grove, Oreg. and Trail, Oreg.	Occasional rough rime and snow - about 2.75 in. on stick
12,900	64	4	62	2.6	.2	2.2	.2	25	.6	226	-1	1/8/52	1205 PST	Between Cottage Grove, Oreg. and Trail, Oreg.	Occasional rough rime and snow - about 2.75 in. on stick
11,100	21	1	21	8.0	.5	8.0	.6	21	.7	247	-9	1/22/52	1705 PST	Over Cottage Grove, Oreg.	Trace of mixed ice
6,300	6	1	6	3.6	.3	3.8	.3	6	.1	180	-4	1/24/52	0328 PST	Near Red Bluff, Calif.	Trace of ice
7,300/8,300	63	1	53	11.2	.9	11.6	.9	63	3.0	211	-4	1/8/52	1722 CST	South Bend, Ind. to Goshen, Ind.	Light to moderate rough ice
11,300	76	1	76	6.6	.4	6.6	.4	76	2.1	241	-6	1/8/52	1852 EST	Brookville, Pa. to Selinsgrove, Pa.	Light rough ice
6,400/8,400	92	2	88	7.7	.6	9.1	.7	41	3.4	206	-3	1/9/52	0257 EST	Wilkes-Barre, Pa. to Selinsgrove, Pa.	Light to moderate rough mixture
8,200	147	2	130	8.6	.6	12+	.9+	74	5.3	210	-4	1/9/52	0348 EST	Phillipsburg, Pa. to Mercer, Pa.	Light to moderate rough mixture
7,100	58	2	55	6.1	.4	4.0	.3	53	1.5	218	-6	1/23/52	0645 CST	Over Des Moines, Iowa	Light rime ice
12,100	92	2	81	6.7	.5	7.1	.5	65	2.4	231	-8	1/31/52	1405 MST	Evanston, Wyo. to Elko, Nev.	No comments
6,500	53	2	34	5.9	.4	4.9	.3	19	.9	222	-9	2/7/52	1441 EST	Sandusky, Ohio to Toledo, Ohio	Trace of ice
7,400	84	4	65	4.7	.3	7.2	.6	18	1.2	219	-7	2/14/52	0225 to 0326 CST	Hayes Center, Nebr. to Lexington, Nebr.	Light rough rime mix in top of overcast
7,000	11	1	11	1.8	.1	1.8	.1	11	.1	222	-5	2/14/52	0417 CST	North of Kearney, Nebr.	Very little ice
7,200	70	5	37	2.2	.2	5.7	.5	11	.4	222	-8	2/14/52	0430 CST	Near Grand Island, Nebr.	Trace of ice
7,400	48	1	48	8.1	.6	8.1	.6	48	1.3	221	-5	2/14/52	0632 CST	Over Moline, Ill.	Picked up about 1/2 in. rime in 12 min
12,000/14,700	22	1	22	4.0	.3	4.0	.3	22	.6	191	-8	1/24/52	2000 PST	Sacramento, Calif. to Reno, Nev.	Night flight. Hard to tell when in icing
15,900	14	1	14	4.5	.3	4.5	.3	14	.3	214	-9	1/24/52	2200 to 2300 MST	Fort Bridger, Wyo. to Sinclair, Wyo.	Night flight. Hard to tell when in icing
14,100	183	5	141	7.8	.5	8.8	.6	102	4.8	211	-9	1/24/52	2200 to 2300 MST	Fort Bridger, Wyo. to Sinclair, Wyo.	Night flight. Hard to tell when in icing
5,300	67	2	25	2.3	.2	2.9	.2	18	.3	222	-5	1/25/52	0905 to 1051 EST	Archbold, Ohio to Toledo, Ohio	Trace of ice
12,800	104	4	97	7.8	.6	8.1	.6	23	3.2	232	-12	1/26/52	0344 to 0543 MST	Fort Bridger, Wyo. to Battle Mountain, Nev.	3/4 in. rime ice with ice crystals
12,600	100	2	84	7.6	.5	8.2	.4	60	2.8	220	-6	1/29/52	0135 PST	Fort Jones, Calif. to Redding, Calif.	Light ice
9,600/11,000	38	1	38	6.9	.5	6.9	.5	38	1.1	230	-8	2/11/52	0320 PST	Siskiyou Mountains, Oreg.	Light rime - 1/2 in. on ice stick
5,500	51	2	45	3.0	.3	2.8	.2	26	.7	192	-7	2/11/52	1045 PST	Seattle, Wash. to Portland, Oreg.	Trace of rime
7,300/8,800	48	2	38	4.0	.3	5.4	.4	25	.8	218	-5	2/14/52	2250 PST	Toledo, Wash.	Trace to light icing
15,400	35	1	36	5.6	.4	5.6	.4	36	1.0	207	-15	2/22/52	1650 PST	Williams, Calif. to Donner Summit, Calif.	Light to moderate clear ice
15,400	[illegible]	1	18	[illegible]	[illegible]	[illegible]	[illegible]	18	[illegible]	[illegible]	[illegible]	[illegible]	[illegible] MST	Promontory, [illegible], Utah	Trace of clear ice
9,100/7,300	137	[illegible]	65	4.6	.4	7.2	.5	14	[illegible]	302	[illegible]	[illegible]	1308 PST	Camp Roberts, Calif. to San Francisco, Calif.	Light glaze - about 1/2 in. on ice stick
10,000	100	4	67	6.0	.4	4.0	.3	60	1.5	222	-9	1/26/52	0800 to 1000 CST	Chicago, Ill. to Iowa City, Iowa	Trace intermittent ice - visible on wings
17,600	6	1	6	4.4	.3	4.4	.3	6	.2	247	-10	1/26/52	1400 to 1800 MST	Eagle, Colo. to Las Vegas, Nev.	Uncertain duration - slight trace of ice
9,200	65	1	65	6.2	.4	6.2	.4	53	1.5	230	-6	2/3/52	0656 CST	Grand Island, Nebr.	Light rime - lost 25 mph indicated airspeed
3,600/3,600	7	1	7	4.0	.4	4.0	[illegible]	7	.1	203	[illegible]	[illegible]	0547 CST	Grand Island, Nebr. to Omaha, Nebr.	Trace of ice in stratocumulus tops
6,000/2,100	45	2	18	6.1	.5	7.7	.7	12	.6	185	-6	2/8/52	0545 EST	Cleveland, Ohio	Trace of ice descending through overcast
6,200	35	1	35	6.1	.5	6.1	.5	35	1.0	210	-2	2/12/52	1148 EST	Selinsgrove, Pa.	Trace of clear ice
6,600	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0800 CST	Moline, Ill. to Iowa City, Iowa	Light to moderate icing
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0000 CST	North Platte, Nebr. to Omaha, Nebr.	No comments
5,800/3,300	32	1	32	2.4	.2	2.4	.2	32	.5	195	-12	3/23/52	0301 CST	Aurora, Ill.	Trace to light icing
7,500	92	4	41	3.5	.3	4.1	.5	28	.5	207	-4	3/12/52	2310 PST	Santa Maria, Calif.	Trace of icing
8,500	56	3	25	5.8	.4	6.1	.5	14	.8	210	-5	3/13/52	0420 PST	Medford, Oreg. to Eugene, Oreg.	Trace - mixture ice and snow
5,500	36	3	18	1.5	.1	1.4	.1	14	.2	212	-5	3/13/52	1941 PST	Oceanside, Calif. to Balboa, Calif.	Trace of icing
5,600/8,300	18	1	18	3.5	.3	3.5	.3	18	.4	184	-14	3/14/52	0900 PST	Oakland, Calif. to Los Angeles, Calif.	Trace of rime and snow mixture
9,000	24	1	24	11.1	.7	11.1	.7	24	1.1	240	-3	3/18/52	0618 MST	Akron, Colo. to North Platte, Nebr.	Light rime ice
6,800/8,400	22	1	22	12+	.9+	12+	.9+	22	1.2	218	-4	3/20/52	0017 EST	Poughkeepsie, N. Y.	Light rime ice
11,300	38	2	16	8.7	.7	8.3	.6	11	.7	211	-6	4/18/52	0430 MST	E of Fort Bridger, Wyo.	Trace rime in stratocumulus clouds
12,400	115	4	46	4.0	.3	5.1	.3	20	.8	246	-12	4/14/52	0300 to 0400 MST	Elko, Utah to Lewis, Utah	Light rough ice - mixture ice and snow
13,100	11	1	11	6.3	.4	6.3	.4	11	.3	219	-6	4/21/52	0222 MST	Two Rivers, Wyo.	Trace rime ice
11,400/12,600	18	1	11	3.1	.2	3.0	.2	7	.2	213	-6	4/21/52	0332 MST	Medicine Bow, Wyo.	Trace rime ice
12,000	137	4	113	4.3	.3	5.0	.4	88	2.3	219	-8	4/21/52	0302 to 0450 MST	Elk Mountain, Wyo. to Elko, Nev.	Light rime ice

[a]Two altitudes separated by / indicate beginning and end of icing during climb or descent.

TABLE I. - Continued. MEASUREMENTS AND CORRELATED OBSERVATIONS OF ICING CONDITIONS ENCOUNTERED DURING ROUTINE AIRLINE OPERATIONS FROM NOVEMBER 1951 THROUGH JUNE 1952

(b) East Coast (U. S.) routes

Pressure altitude,[a] ft	Horizontal extent of encounter, mi	Number of icing incidents for encounter	Total horizontal icing, mi	Average icing rate for all icing incidents, in./hr	Average liquid-water content for all icing incidents, g/cu m	Maximum continuous icing incident within encounter: Average icing rate, in./hr	Average liquid-water content, g/cu m	Horizontal extent, mi	Calculated total ice accumulation, in.	Average true airspeed, mph	Corrected air temperature, °C	Date	Time (local)	Location of encounter	Flight observations and comments
20,200/16,400	135	3	84	6.5	0.4	7.0	0.4	70	2.0	279	-18	11/12/51	1030 CST	W of Jackson, Miss.	No comments
16,000/11,900	76	2	61	5.2	.3	4.9	.3	56	1.1	303	-18	11/13/51	1125 EST	20 Mi NNE of Norfolk, Va.	Skimming tops at 15,500 ft - clear 10,000 ft
10,700/13,500	25	2	15	7.4	.6	10.0	.7	8	.5	229	---	11/13/51	1426 EST	Vicinity of Lakehurst, N. J.	Climb through cloud deck
7,200	17	1	17	9.4	.6	9.4	.6	17	.6	260	-2	11/15/51	1550 EST	Vicinity of Wabash River, Ind.	No comments
7,800/7,300	19	1	19	10.2	.5	10.2	.5	19	.7	234	-17	11/20/51	1703 EST	Between Cleveland, Ohio and Ypsilanti, Mich.	No comments
18,700	9	1	9	2.3	.1	2.3	.1	9	.1	311	-9	11/25/51	0322 to 0335 EST	------------------------	No comments
14,400	327	8	154	2.5	.1	2.3	.1	54	1.3	287	-2	12/4/51	1200 EST	Miami, Fla. to Washington, D. C.	No comments
12,800	9	1	9	4.7	.2	4.7	.2	9	.2	318	-2	12/8/51	1145 CST	15 Mi S of Chicago, Ill.	No comments
4,400/3,400	23	1	23	6.8	.4	6.8	.4	23	.8	181	0	----------	1340 CST	SW of St. Louis, Mo.	No comments
4,400/5,100	8	1	8	8.7	.6	8.7	.6	8	.4	155	---	12/9/51	1654 CST	St. Louis, Mo. to Louisville, Ky.	No comments
5,800/4,700	7	1	7	12+	.9+	12+	.9+	7	.4	234	-1	12/9/51	1735 CST	E of Louisville, Ky.	No comments
6,100	33	2	14	5.7	.3	5.6	.5	10	.3	266	-6	12/9/51	1945 EST	Over Philadelphia, Pa.	No comments
4,900/7,000	54	2	50	3.7	.2	3.8	.2	17	.4	262	-2	12/10/51	1040 EST	W of Washington, D. C.	No comments
14,200	23	1	25	6.8	.4	6.8	.4	25	.6	292	-7	12/14/51	1820 EST	Atlanta, Ga. to New York, N. Y.	Light precipitation
14,800/10,100	450	8	233	1.8	.1	1.5	.1	110	1.3	300	-7	12/14/51	1945 EST	Atlanta, Ga. to New York, N. Y.	Light ice on windshield and wings
6,100/9,500	151	4	102	8.0	.4	9.6	.6	78	2.9	275	-2	12/18/51	1400 EST	Newark, N. J. to Washington, D. C.	Heavy icing
13,500	124	1	124	2.5	.1	2.5	.1	124	1.0	311	-6	12/20/51	2000 EST	Near Newark, N. J.	Light icing
13,700	10	1	10	7.8	.4	7.8	.4	10	.3	292	-10	1/4/52	1715 CST	35 Mi E of Birmingham, Ala.	No comments
13,500	65	2	24	4.8	.3	3.7	.2	20	.4	293	-2	1/4/52	2025 CST	------------------------	No comments
3,800/2,800	9	1	9	8.5	.6	8.5	.6	9	.6	141	-1	1/6/52	----------	Over Louisville, Ky.	No comments
3,000/3,800	8	1	8	6.8	.4	6.8	.4	8	.2	236	-3	1/6/52	2332 CST	Near Louisville, Ky.	No comments
3,500	11	1	11	7.4	.4	7.4	.4	11	.6	160	-2	1/7/52	1530 EST	Franklin, Mass. to Boston, Mass.	Snow
12,800	15	1	15	.6	.1	.6	.1	15	.1	295	-5	1/8/52	1130 EST	10 Mi S of Charlotte, N. C.	No comments
11,300	8	1	8	8.6	.6	8.6	.6	8	.3	225	-3	1/9/52	0048 EST	Lakehurst, N. J. to Atlantic City, N. J.	Some snow
14,500	12	1	12	1.6	.1	1.6	.1	12	.1	240	-7	1/9/52	2010 EST	Rocky Mount, N. C.	No comments
13,100	26	1	26	4.2	.3	4.2	.3	26	.4	275	-4	1/12/52	1442 EST	Greensboro, N. C. to Blackstone, Va.	No comments
20,200	82	4	22	4.8	.3	1.0	.1	9	.4	258	-20	2/13/52	2130 CST	Louisville, Ky. to Atlanta, Ga.	Constant icing and turbulence
20,300	9	1	9	8.5	.5	8.5	.5	9	.3	260	-20	2/13/52	2155 CST	Louisville, Ky. to Atlanta, Ga.	Constant icing and turbulence
11,800	121	4	65	1.7	.1	1.7	.1	26	.4	260	-6	2/15/52	1146 to 1158 EST	Over Lumberton, N. C.	Rain and slight slushy ice
14,800	120	2	80	3.2	.2	4.1	.2	60	.9	301	-5	2/15/52	2000 EST	Richmond, Va. to Rocky Mount, N. C.	Moderate to heavy icing
12,200	36	2	32	2.2	.1	2.7	.2	23	.3	272	-12	2/16/52	0230 EST	150 Mi off coast Jacksonville, Fla.	No comments
17,700/9,100	291	7	78	3.1	.2	2.4	.1	28	.9	277	-15	2/18/52	1320 EST	Huntington, W. Va. to Louisville, Ky.	No comments
11,400/12,800	227	6	180	2.8	.2	3.7	.2	87	1.5	290	-1	1/27/52	2125 EST	From Susquehanna River to Washington, D. C.	No comments
13,400	329	9	200	4.5	.2	5.1	.3	67	3.2	206	-4	1/26/52	0050 CST	Between Birmingham, Ala. and Jackson, Miss.	No comments
12,800/2,000	57	3	25	3.7	.3	2.1	.2	13	.5	190	-10	1/26/52	1345 EST	Washington, D. C. to Newark, N. J.	Icing from 19,000 ft down to ground
15,100	20	1	20	.8	.1	.8	.1	20	.1	286	-15	1/28/52	1730 EST	20 Min S of Newark, N. J.	No comments
11,800	59	2	39	3.1	.2	2.2	.2	34	.4	294	-2	1/30/52	0914 CST	30 Min E of Houston, Tex.	No comments
14,400	91	1	91	10.6	.6	10.6	.6	91	5.4	286	-4	2/1/52	1600 CST	Between Alexandria, La. and Beaumont, Tex.	No comments
5,900	4	1	4	6.1	.3	6.1	.3	4	.1	257	---	2/20/52	2238 EST	Cleveland, Ohio to Detroit, Mich.	Thin ice on boots, visible only on ground
15,900	167	4	115	3.8	.2	5.0	.3	57	1.5	287	-12	2/24/52	0803 EST	125 Mi due E Lakehurst, N. J.	No comments
5,600	47	1	47	1.6	.1	1.6	.1	47	.3	259	-7	----------	1640 EST	Between Cleveland, Ohio and Ypsilanti, Mich.	Scattered snow
3,700/3,100	13	1	13	4.3	.3	4.3	.3	13	.3	186	-9	3/7/52	1840 EST	Between Ypsilanti, Mich. and Cleveland, Ohio	Heavy overcast
9,700/11,400	14	1	14	6.1	.5	6.1	.5	14	.3	274	-9	3/9/52	0445 CST	Over Louisville, Ky.	No comments
6,900/9,000	17	1	17	7.5	.6	7.5	.6	17	.5	261	-2	3/10/52	1020 CST	Out of Chicago, Ill.	Light rain
3,100/6,900	36	2	26	5.3	.4	5.4	.4	16	.7	198	-2	3/14/52	1235 EST	Out of LaGuardia Field, N. Y.	Light rain
16,000	15	1	15	1.5	.1	1.5	.1	15	.1	293	-2	3/26/52	1015 EST	100 Mi E of N. J. coast	No comments

[a]Two altitudes separated by / indicate beginning and end of icing during climb or descent.

TABLE I. - Continued. MEASUREMENTS AND CORRELATED OBSERVATIONS OF ICING CONDITIONS ENCOUNTERED DURING ROUTINE AIRLINE OPERATIONS FROM NOVEMBER 1951 THROUGH JUNE 1952

(c) Northeastern (U.S.) routes

Pressure altitude,[a] ft	Horizontal extent of encounter, mi	Number of icing incidents for encounter	Total horizontal icing, mi	Average icing rate for all icing incidents, in./hr	Average liquid-water content for all icing incidents, g/cu m	Maximum continuous icing incident within encounter: Average icing rate, in./hr	Maximum continuous icing incident within encounter: Average liquid-water content, g/cu m	Maximum continuous icing incident within encounter: Horizontal extent, mi	Calculated total ice accumulation, in.	Average true airspeed, mph	Corrected air temperature, °C	Date	Time (local)	Location of encounter	Flight observations and comments
6,800/7,900	15	2	8	8.0	0.8	9.2	0.9	5	0.4	181	-3	2/1/52	2126 EST	Over Huntington, Vt.	No comments
5,200	18	1	18	9.8	1.0	9.8	1.0	18	1.2	154	-3	2/2/52	1120 EST	Lebanon, N. H. to Northfield, Vt.	Rapid ice accumulation
8,400/3,000	56	3	21	5.4	.5	5.2	.5	12	.6	176	-9	2/2/52	1815 EST	Northfield, Vt. to Burlington, Vt.	Light icing
4,300	6	1	6	6.6	.5	6.6	.5	6	.2	169	-2	2/5/52	1813 EST	Near Presque Isle, Maine	No ice visible
3,200/2,100	44	2	26	3.5	.3	3.8	.4	23	.6	156	-3	2/7/52	0817 EST	Woodstock Conn. to Worcester, Mass.	No comments
4,100/3,300	55	2	39	6.6	.6	7.7	.7	22	1.7	165	-8	2/7/52	0916 EST	Woodstock, Conn. to North Scituate, Mass.	Light to moderate rough accumulation
1,600/2,200	37	2	18	3.0	.3	3.6	.4	8	.3	158	-4	2/7/52	1006 EST	Boston, Mass. to Portsmouth, N. H.	Light rime on windshield and boots
2,200/1,000	52	2	41	7.0	.7	8.1	.8	24	1.8	183	-5	2/7/52	1557 EST	Squantum, Mass. to Hyannis, Mass.	Light icing
7,100/5,500	38	3	29	4.1	.4	5.6	.5	14	.7	173	-6	2/11/52	1800 EST	Montpelier, Vt. to Burlington, Vt.	Very thin ice
2,400	21	1	21	3.8	.4	3.8	.4	21	.5	160	-5	2/11/52	2000 EST	Montreal, Que. to Burlington, Vt.	Very thin ice
2,900/2,200	11	1	11	7.7	.7	7.7	.7	11	.5	170	-3	2/16/52	1842 EST	New Canaan, Conn. to Port Chester, N. Y.	Trace of ice
6,300/4,500	9	1	9	4.0	.3	4.0	.3	9	.2	185	-9	2/19/52	1845 EST	Montpelier, Vt. to Burlington, Vt.	Trace of ice
4,500/6,500	15	1	15	6.3	.7	6.3	.7	15	.6	148	-14	2/19/52	2105 EST	Out of Burlington, Vt.	Light rime
4,000	3	1	3	12+	1.1+	12+	1.1+	3	.2	183	-8	2/22/52	1445 EST	Salem, Conn. to Providence, R. I.	Light rime
1,800	12	1	12	6.1	.7	6.1	.7	12	.5	142	-9	2/22/52	1854 EST	Over Bedford, Mass.	Trace of ice
2,200/3,200	52	2	39	5.8	.6	8.0	.5	21	1.5	157	-8	2/25/52	0850 EST	Worcester, Mass. to Boston, Mass.	Light rime
3,600/3,000	30	2	5	7.3	.7	12+	1.5+	2	.2	159	-6	2/27/52	1515 EST	Haverhill, Mass to Boston, Mass.	Trace of ice
5,200	9	1	9	12.0	1.1	12.0	1.1	9	.8	171	-2	3/7/52	1814 EST	Providence, R. I. to Moosup, Conn.	Rapid ice accumulation
5,200/600	57	2	22	6.3	.6	6.3	.8	14	.9	167	---	3/7/52	1856 EST	Over Port Chester, N. Y.	Rapid ice accumulation
4,000/4,800	8	1	8	10.7	1.5	10.7	1.5	6	.4	166	-9	3/7/52	2555 EST	Between New York, N. Y. and Bridgeport, Conn.	Rapid ice accumulation
5,100/3,300	13	1	13	10.6	1.0	10.6	1.0	13	.9	157	-8	3/7/52	2420 EST	Between New York, N. Y. and Bridgeport, Conn.	Rapid ice accumulation
4,900/3,600	16	1	16	7.4	.7	7.4	.7	16	.6	164	-20	3/9/52	1255 EST	Bedford, Mass. to Boston, Mass.	Light icing
5,800	132	7	41	4.5	.4	3.3	.3	14	1.2	162	-14	3/9/52	1355 EST	Boston, Mass. to Hartford, Conn.	Light icing
2,300	6	1	6	9.8	.9	9.8	.9	6	.3	165	-2	3/9/52	1612 EST	Over Worcester, Mass.	No comments
2,500	22	1	22	5.9	.6	5.9	.6	22	.6	164	-2	3/9/52	1700 EST	Out of Worcester, Mass.	No comments
6,300/5,800	11	1	11	5.0	.5	5.0	.5	11	.3	169	-12	3/13/52	1728 EST	Over Burlington, Vt.	No comments
1,700/1,200	57	3	16	1.8	[illegible]	2.7	.3	8	.2	164	-4	3/19/52	1817 EST	Between Boston, Mass. and Portland, Maine	Light ice
2,600	60	2	41	4.6	.4	4.8	.5	38	1.2	168	-5	3/19/52	2126 EST	Between Bangor, Maine and Presque Isle, Maine	Light ice
3,800/5,800	30	1	30	6.5	.7	6.5	.7	30	1.2	164	-5	3/20/52	1500 EST	Presque Isle, Maine to Bangor, Maine	Light ice
8,000	9	1	9	5.0	.5	5.0	.5	9	.2	173	-3	3/21/52	1630 EST	Concord, N. H. to Burlington, Vt.	Very light rime
6,000	24	3	19	4.1	.4	5.7	.6	8	.5	163	-6	3/21/52	1730 EST	Burlington, Vt. to S. of Montpelier, Vt.	Very light rime
2,000/1,500	21	1	21	3.8	.4	3.8	.4	21	.5	159	-2	3/24/52	0926 EST	Boston, Mass. to Concord, N. H.	Very light rime
4,800/2,200	53	2	37	3.7	.4	3.9	.4	27	.9	159	-4	3/24/52	0955 EST	Concord, N. H. to Lebanon, N. H.	Very light rime

[a]Two altitudes separated by / indicate beginning and end of icing during climb or descent.

TABLE I. - Concluded. MEASUREMENTS AND CORRELATED OBSERVATIONS OF ICING CONDITIONS ENCOUNTERED DURING ROUTINE AIRLINE OPERATIONS FROM NOVEMBER 1951 THROUGH JUNE 1952

(d) Transcontinental Canada routes

Pressure altitude,[a] ft	Horizontal extent of encounter, mi	Number of icing incidents for encounter	Total horizontal icing, mi	Average icing rate for all icing incidents, in./hr	Average liquid-water content for all icing incidents, g/cu m	Maximum continuous icing incident within encounter: Average icing rate, in./hr	Average liquid-water content, g/cu m	Horizontal extent, mi	Calculated total ice accumulation, in.	Average true airspeed, mph	Corrected air temperature, °C	Date	Time (local)	Location of encounter	Flight observations and comments
4,800	1	1	1	7.9	0.9	7.9	0.9	1	0.1	148	-3	11/20/51	0840 MST	Approach to Saskatoon, Sask.	No comments
18,500	37	1	37	5.8	.4	5.8	.4	37	.9	248	-26	11/21/51	2210 PST	Over Crescent Valley, B. C.	Ice on windshield
8,200/8,500	61	3	34	7.0	.5	7.1	.5	23	1.1	228	-4	11/23/51	0040 EST	Between Wiarton, Ont. and Gore Bay, Ont.	No comments
13,400	16	2	7	4.1	.3	5.0	.3	4	.1	240	-21	11/23/51	2015 EST	Between St. John's, Newf. and Montreal, Que.	Trace of rime in altostratus cloud
8,000	65	3	33	4.8	.4	7.4	.5	15	.7	222	-13	11/25/51	0100 EST	Over Lake Superior	No comments
13,900	28	2	8	1.8	.1	1.6	.1	6	.1	168	-6	12/4/51	1515 EST	10 Mi E of London, Ont.	No comments
(e) Pacific Coast route: Seattle, Washington to Alaska															
9,000	147	10	80	1.9	0.2	2.7	0.2	37	0.8	201	-6	1/26/52	0850 PST	Pat Bay, B. C. to Comox, B. C.	Light to moderate glaze
5,300/11,600	153	5	80	2.1	.2	2.7	.2	23	.7	199	-6	1/26/52	0850 PST	Pat Bay, B. C. to Comox, B. C.	No comments
11,100	6	1	6	1.9	.1	1.9	.1	6	.1	215	-8	1/26/52	0850 PST	Pat Bay, B. C. to Comox, B. C.	No comments
4,500/10,700	112	5	60	1.8	.1	2.2	.2	27	.6	201	-10	1/26/52	0850 PST	Pat Bay, B. C. to Comox, B. C.	No comments
8,100/5,800	41	2	21	1.7	.1	2.8	.2	14	.2	205	-10	1/26/52	0850 PST	Pat Bay, B. C. to Comox, B. C.	No comments
5,300	6	1	6	1.5	.1	1.5	.1	6	.1	203	-10	1/26/52	0850 PST	Pat Bay, B. C. to Comox, B. C.	No comments
9,800	15	1	15	1.6	.1	1.6	.1	15	.1	219	-8	1/28/52	0205 PST	Pat Bay, B. C. to Comox, B. C.	No comments
10,000	65	3	28	2.6	.2	3.5	.3	11	.4	217	-6	1/28/52	0225 PST	Pat Bay, B. C. to Comox, B. C.	No comments
6,400	88	2	31	2.6	.2	2.2	.2	24	.4	208	-6	1/28/52	0250 PST	Pat Bay, B. C. to Comox, B. C.	No comments
6,900	4	1	4	5.0	.4	5.0	.4	4	.1	218	-8	1/31/52	0750 PST	Pat Bay, B. C. to Comox, B. C.	No comments
8,100	6	1	5	4.1	.3	4.1	.3	6	.1	194	-8	1/31/52	0810 PST	Pat Bay, B. C. to Comox, B. C.	No comments
7,100/2,500	54	2	17	1.1	.1	1.4	.1	11	.1	170	-7	2/7/52	1016 PST	Banks, B. C. to Annette Island, Alaska	Trace of ice
2,800/8,300	30	1	30	1.9	.2	1.9	.2	30	.3	201	-9	2/7/52	1505 PST	Annette Island to Gustavus, Alaska	Light freezing rain at start of climb
7,800/8,500	17	1	17	2.7	.2	2.7	.2	17	.2	206	-8	2/7/52	1730 PST	Sisters Island, Alaska to Haines, Alaska	Light clear ice
10,700	183	5	69	2.2	.2	2.9	.2	36	.7	217	-13	2/13/52	0315 PST	Lyell, B. C. intersection	Light rime, lost 25 mph airspeed
11,800	10	1	10	2.1	.2	2.1	.2	10	.1	204	-27	2/14/52	1430 PST	Between Gustavus, Alaska and Haines, Alaska	Trace of rime
10,300	8	1	8	1.0	.1	1.0	.1	8	.1	226	---	2/16/52	--------	Over Port Gamble, Wash.	Trace of rime
7,800/5,600	24	1	24	2.5	.2	2.9	.2	24	.3	205	-8	3/2/52	1500 PST	Over Annette Island, Alaska	Trace of rime
8,700	78	3	22	3.3	.2	2.1	.2	11	.3	224	-11	3/2/52	1600 PST	Baker Lake, N.W.T. to Lyell, B. C.	Total accumulation considered trace
8,700	33	1	33	1.3	.1	1.3	.1	33	.2	200	-5	3/7/52	1145 PST	Annette Island, Alaska to Petersburg, Alaska	Very soft ice
9,500	27	1	27	2.7	.2	2.7	.2	27	.4	206	-5	3/7/52	1245 PST	Over Juneau, Alaska	No comments
10,000	77	2	66	3.0	.2	3.2	.2	49	1.0	209	-3	3/8/52	2530 PST	100 Mi N of Port Hardy, Vancouver Island	Airspeed dropped from 182 to 160 mph
10,700	151	5	48	3.7	.3	4.7	.3	18	.8	221	-11	4/12/52	0216 PST	Near Quenn Charlotte Straits	Mixed rime and snow
10,600	11	1	11	2.5	.2	2.5	.2	11	.1	227	-9	4/12/52	0330 PST	Near Queen Charlotte Straits	Rime ice, used 800 hp
10,600	4	1	4	4.8	.3	4.6	.3	4	.1	220	-13	4/12/52	0400 PST	Near Petersburg, Alaska	Light rime
6,500/9,200	26	2	13	3.7	.3	4.9	.4	10	.3	192	-3	4/18/52	0855 PST	4 Mi S of Comox, B. C.	Intermittent light rime
6,900/10,100	206	6	20	3.5	.3	2.8	.2	10	.5	209	-4	4/18/52	1015 PST	4 Mi S of Comox, B. C.	No comments
8,900	7	1	7	2.3	.2	2.3	.2	7	.1	219	-6	4/19/52	--------	--------------------------------	Intermittent icing
8,200/4,900	60	1	60	3.4	.3	3.4	.3	60	1.0	211	-18	4/28/52	--------	Seattle, Wash. to Juneau, Alaska	Light icing
9,800/11,900	71	2	25	3.1	.2	2.1	.2	14	.4	213	-18	4/28/52	--------	Seattle, Wash. to Juneau, Alaska	Light icing

[a] Two altitudes separated by / indicate beginning and end of icing during climb or descent.

TABLE II. - MEASUREMENTS ONLY OF ICING CONDITIONS ENCOUNTERED DURING ROUTINE AIRLINE OPERATIONS FROM NOVEMBER 1951 THROUGH JUNE 1952

(a) Transcontinental and Pacific Coast (U.S.) routes

Pressure altitude,[a] ft	Horizontal extent of encounter, mi	Number of icing incidents for encounter	Total horizontal distance in icing, mi	Average icing rate for all icing incidents, in./hr	Average liquid-water content for all icing incidents, g/cu m	Maximum continuous icing incident within encounter			Calculated total ice accumulation, in.	Average true airspeed, mph
						Average icing rate, in./hr	Average liquid-water content, g/cu m	Horizontal extent, mi		
4,100	75	4	30	3.9	0.4	6.8	0.5	16	0.7	197
5,000	6	1	6	7.8	.7	7.8	.7	6	.3	192
5,200	8	1	7	3.7	.2	3.7	.2	7	.1	231
8,100	58	3	27	2.9	.2	2.5	.2	14	.4	204
13,400/14,200	13	1	13	4.9	.4	4.9	.4	13	.3	192
15,800	15	1	15	3.8	.2	3.8	.2	15	.2	230
15,000/14,100	16	1	16	10.5	.7	10.5	.7	16	.7	233
13,600	40	1	40	6.1	.4	6.1	.4	40	1.3	237
11,400/10,300	21	2	13	1.4	.1	1.9	.1	13	.1	254
12,600/11,800	23	1	23	6.1	.4	6.1	.4	23	.6	226
9,800	17	1	17	1.4	.1	1.4	.1	17	.1	249
8,900	50	2	38	6.6	.5	6.4	.5	31	1.2	230
12,600	8	1	8	3.9	.2	3.9	.2	8	.1	251
13,100	56	1	56	3.1	.2	3.1	.2	56	.7	242
12,900	56	2	49	10.4	.7	10.3	.7	45	2.3	224
10,700/5,400	68	2	60	4.5	.3	5.0	.4	50	1.3	213
5,400	4	1	4	1.6	.1	1.6	.1	4	.1	214
11,300	8	1	8	5.4	.4	5.4	.4	8	.2	244
8,100	20	1	20	3.2	.2	3.2	.2	20	.3	197
8,500	7	1	7	1.5	.1	1.5	.1	7	.1	221
6,900	8	1	8	8.5	.6	8.5	.6	8	.3	225
3,600/2,300	26	1	26	7.5	.6	7.5	.6	26	1.4	141
3,300	6	1	6	10.5	1.0	10.5	1.0	6	.4	165
2,700	12	1	12	1.6	.1	1.6	.1	12	.1	184
4,000/2,400	12	1	12	9.9	.7	9.9	.7	12	.7	184
3,700	3	1	3	7.5	.6	7.5	.6	3	.1	197
4,800	8	1	8	6.1	.4	6.1	.4	8	.2	229
7,100/4,900	29	2	21	7.6	.5	4.7	.3	12	.6	250
9,700/7,400	18	1	18	3.9	.2	3.9	.2	18	.3	269
13,300	50	1	50	4.2	.3	4.2	.3	50	1.1	230
6,100	12	1	12	3.2	.2	3.2	.2	12	.2	230
8,300/7,100	17	1	17	7.8	.5	7.8	.5	17	.6	204
8,100	8	1	8	2.1	.2	2.1	.2	8	.1	228
5,400/6,000	6	1	6	3.8	.4	3.8	.4	6	.1	174
6,500/5,000	21	2	11	1.0	.1	1.0	.1	14	.1	214
13,500	54	3	14	3.5	.2	3.2	.2	7	.2	217
12,600	29	1	29	4.4	.3	4.4	.3	29	.7	221
13,400	77	1	77	5.9	.5	5.9	.5	77	2.3	193
13,400	63	2	54	6.2	.5	6.3	.5	31	1.8	189
13,400	28	2	18	4.2	.3	4.8	.4	14	.4	212
12,000	171	3	151	8.3	.6	6.9	.5	77	6.3	210
11,000	42	1	42	4.2	.3	4.2	.3	42	.8	227
8,900	151	5	95	5.8	.4	8.3	.6	42	2.7	227
6,300/3,200	47	2	41	7.2	.5	12+	1.0+	32	1.7	189
5,100/6,400	8	1	8	11.0	1.1	11.0	1.1	8	.6	162
4,200/3,500	24	1	24	2.0	.1	2.0	.1	24	.2	235
4,300	100	2	76	7.5	.6	7.8	.6	66	2.8	208
13,000	12	1	12	9.3	.6	9.3	.6	12	.5	231
13,300	12	1	12	4.1	.3	4.1	.3	12	.2	232
3,800	41	1	41	10.5	.8	10.5	.8	41	2.1	203
10,300	8	1	8	9.6	.7	9.6	.7	8	.3	228
5,300	4	1	4	3.0	.2	3.0	.2	4	.1	216
8,300	18	1	18	2.7	.2	2.7	.2	18	.2	213
8,100	66	2	59	8.0	.6	6.8	.5	56	2.4	198

[a]Two altitudes separated by / indicate beginning and end of icing during climb or descent.

TABLE II. - Continued. MEASUREMENTS ONLY OF ICING CONDITIONS ENCOUNTERED DURING ROUTINE AIRLINE OPERATIONS FROM NOVEMBER 1951 THROUGH JUNE 1952

(a) Transcontinental and Pacific Coast (U.S.) routes - Continued

Pressure altitude,[a] ft	Horizontal extent of encounter, mi	Number of icing incidents for encounter	Total horizontal distance in icing, mi	Average icing rate for all icing incidents, in./hr	Average liquid-water content for all icing incidents, g/cu m	Maximum continuous icing incident within encounter: Average icing rate, in./hr	Maximum continuous icing incident within encounter: Average liquid-water content, g/cu m	Maximum continuous icing incident within encounter: Horizontal extent, mi	Calculated total ice accumulation, in.	Average true airspeed, mph
9,600	89	3	58	7.4	0.5	9.4	0.6	35	1.8	232
11,500	16	1	16	8.8	.6	9.8	.6	16	.6	246
6,200/4,700	15	1	15	3.3	.2	3.3	.2	15	.3	220
6,300	60	3	41	4.7	.4	5.3	.4	25	1.2	188
12,300	15	1	15	3.4	.2	3.4	.2	15	.3	229
7,100/10,100	55	2	14	7.7	.6	7.7	.6	10	.5	206
7,000	14	1	14	2.2	.2	2.2	.2	14	.2	208
9,200	47	2	37	3.6	.3	2.9	.2	30	.7	200
12,400	20	1	20	3.7	.2	3.7	.2	20	.3	241
9,300	161	4	111	3.7	.3	4.5	.3	72	2.0	215
4,100	65	1	65	4.5	.4	4.5	.4	65	1.4	202
5,300/5,900	9	1	9	6.6	.6	6.6	.6	9	.3	177
11,800	64	1	64	4.9	.4	4.9	.4	64	1.4	225
9,700/8,300	28	1	28	6.9	.4	6.9	.4	28	.8	240
9,600/3,900	71	2	42	9.1	.6	9.3	.7	35	1.8	212
7,700/3,600	67	3	28	1.6	.1	1.2	.1	18	.3	212
6,100	100	2	92	9.0	.7	8.3	.7	53	4.4	197
8,300	30	1	30	2.8	.2	2.8	.2	36	.4	223
12,400	100	4	57	5.1	.4	7.0	.5	21	1.4	212
10,200/9,700	19	1	19	3.7	.3	3.7	.3	19	.4	227
13,500	8	1	8	2.2	.2	2.2	.2	8	.2	239
4,400/3,000	56	2	40	2.9	.2	2.5	.2	28	.6	198
6,500/1,600	57	7	24	1.3	.1	1.5	.1	14	.3	163
9,200	102	3	23	2.3	.2	2.9	.2	19	.3	227
6,200/2,900	64	4	22	3.9	.3	3.2	.3	10	.5	192
5,300	21	1	21	1.9	.1	1.9	.1	21	.2	208
7,400/2,300	96	3	53	3.3	.3	4.0	.3	40	1.1	198
14,800	15	1	15	6.4	.5	6.4	.5	15	.4	220
2,200/1,500	5	1	5	4.5	.5	4.5	.5	5	.2	140
1,300/2,900	8	1	8	7.4	.7	7.4	.7	8	.4	163
5,100/5,800	7	1	7	4.8	.4	4.8	.4	7	.2	221
9,200/11,400	69	3	29	4.2	.3	4.8	.3	29	.7	217
4,000	26	1	26	6.7	.5	6.7	.5	26	1.0	197
5,000	9	1	9	6.8	.6	6.8	.6	9	.4	189
5,600/7,600	24	1	24	10.3	.9	10.3	.9	24	1.4	205
11,400	25	2	22	10.1	.8	9.2	.7	14	1.0	215
13,700	270	7	45	4.5	.3	5.6	.4	19	1.0	225
9,700/7,600	84	2	46	7.0	.5	7.7	.5	38	1.4	228
9,700	119	3	31	8.7	.6	7.8	.5	23	1.3	231
6,500	75	2	56	5.2	.3	4.8	.3	44	1.4	238
13,200	11	1	11	4.3	.3	4.3	.3	11	.3	221
10,000/7,100	71	2	49	3.7	.3	3.9	.3	35	.8	212
9,500/10,700	66	1	66	5.7	.4	5.7	.4	66	1.8	209
11,500	23	1	23	8.9	.6	8.9	.6	23	1.0	227
13,600	63	2	48	8.1	.6	7.1	.5	37	1.9	221
5,900	22	1	22	5.9	.4	5.9	.4	22	.6	219
10,900	31	1	31	2.1	.1	2.1	.1	31	.3	230
6,500	4	1	4	9.7	.7	9.7	.7	4	.2	226
8,800	65	1	65	9.4	.7	9.4	.7	65	2.8	216
6,900	34	2	11	2.2	.2	2.8	.2	8	.1	225
5,600/4,100	16	1	16	3.4	.2	3.4	.2	16	.2	243
4,600/5,000	7	1	7	7.0	.6	7.0	.6	7	.2	209
6,400	37	1	37	9.2	.7	9.2	.7	37	1.7	202
4,600/3,700	16	1	16	5.7	.5	5.7	.5	16	.5	189

[a]Two altitudes separated by / indicate beginning and end of icing during climb or descent.

TABLE II. - Continued. MEASUREMENTS ONLY OF ICING CONDITIONS ENCOUNTERED DURING ROUTINE AIRLINE OPERATIONS FROM NOVEMBER 1951 THROUGH JUNE 1952

(a) Transcontinental and Pacific Coast (U.S.) routes - Concluded

essure citude,[a] ft	Horizontal extent of encounter, mi	Number of icing incidents for encounter	Total horizontal distance in icing, mi	Average icing rate for all icing incidents, in./hr	Average liquid-water content for all icing incidents, g/cu m	Maximum continuous icing incident within encounter			Calculated total ice accumulation, in.	Average true airspeed, mph
						Average icing rate, in./hr	Average liquid-water content, g/cu m	Horizontal extent, mi		
4,200/5,000	7	1	7	6.0	0.5	6.0	0.5	7	0.2	222
7,600/4,000	40	1	40	3.8	.3	3.8	.3	40	.7	216
11,400/5,600	169	5	81	3.7	.3	3.0	.2	34	1.6	230
7,700/5,600	106	3	23	5.4	.4	2.8	.2	13	.8	198
6,200/8,400	17	1	17	6.8	.6	6.8	.6	17	.7	174
10,900/8,300	91	3	30	6.5	.4	5.6	.4	19	1.0	228
8,300/6,500	50	3	28	3.9	.3	4.7	.4	18	.6	212
8,500	39	2	28	2.9	.2	2.1	.2	18	.4	213
9,300	8	1	8	4.2	.4	4.2	.4	8	.2	169
11,200	22	1	22	4.8	.4	4.8	.4	22	.5	217
11,000	46	3	31	3.8	.3	3.8	.3	19	.6	232
7,200	4	1	4	4.6	.3	4.6	.3	4	.1	234
6,900/4,500	16	2	9	7.2	.5	7.0	.6	6	.4	186
10,600	4	1	4	2.0	.1	2.0	.1	4	.1	231
5,400/4,800	32	2	25	6.4	.5	6.2	.5	14	.7	212
4,800/8,400	38	2	21	6.5	.5	7.6	.6	14	.6	206
14,700	37	1	37	2.5	.2	2.5	.2	37	.5	247
3,700/2,800	14	1	14	3.9	.3	3.9	.3	14	.3	214
3,700	35	1	35	2.7	.2	2.7	.2	35	.4	208
3,600	22	1	22	1.5	.1	1.5	.1	22	.2	220
7,600	89	1	89	3.7	.3	3.7	.3	89	1.5	223
12,200	25	1	25	2.5	.2	2.5	.2	25	.2	247
10,200/11,500	13	1	13	7.5	.6	7.5	.6	13	.5	190
6,400/8,600	107	2	77	7.5	.6	7.9	.6	66	2.6	221
12,300/11,200	61	1	61	4.3	.3	4.3	.3	61	1.2	227
10,200/9,100	28	1	28	5.6	.4	5.6	.4	28	.8	209
7,300/6,800	9	1	9	3.6	.3	3.6	.3	9	.2	173
13,100	224	7	35	3.8	.2	6.6	.5	8	.7	231
8,300/8,700	33	1	33	11.7	.8	11.7	.8	33	1.8	219
9,700/8,500	11	1	11	9.5	.6	9.5	.6	11	.5	229
6,300/8,400	99	1	99	5.2	.4	5.2	.4	99	2.6	212
7,000	12	1	12	1.5	.1	1.5	.1	12	.1	238
7,100	23	1	23	1.1	.1	1.1	.1	23	.1	233
10,600/11,200	23	2	11	8.1	.6	8.1	.4	8	.4	228
11,200	34	2	15	8.5	.6	8.0	.6	7	.6	224
11,200	53	2	12	7.1	.5	5.3	.4	8	.4	230
7,000/3,700	64	1	64	6.3	.4	6.3	.4	64	2.0	226
6,100/4,200	22	2	11	2.3	.2	3.2	.3	8	.2	167
13,400	38	2	30	2.7	.2	3.3	.2	19	.4	227
11,900	8	1	8	1.9	.1	1.9	.1	8	.1	231
11,900	40	3	22	5.6	.4	4.8	.3	11	.6	221
10,400	39	1	39	12.0	.9	12.0	.9	39	2.2	215
11,100/10,200	25	1	25	3.4	.3	3.4	.3	25	.4	184
10,900/9,600	20	2	11	4.4	.4	5.1	.5	8	.3	170
13,400	24	1	24	2.3	.2	2.3	.2	24	.2	237
11,200	106	2	19	4.6	.3	6.2	.4	15	.5	227
12,200	82	2	66	4.8	.3	4.5	.3	54	1.6	233
1,600/1,500	9	1	9	1.6	.2	1.6	.2	9	.1	138
4,000/8,500	136	3	119	6.5	.5	6.8	.5	51	3.8	204
8,500	41	2	37	1.5	.1	1.5	.1	26	.3	222
1,800/6,000	168	2	158	7.7	.6	7.5	.6	102	6.3	198
6,200/5,200	11	1	11	5.7	.4	5.7	.4	11	.3	215
11,000	91	3	53	4.4	.3	3.0	.2	41	1.1	226
7,100/8,100	37	1	37	8.5	.7	8.5	.7	37	1.6	203

[a]Two altitudes separated by / indicate beginning and end of icing during climb or descent.

3017

TABLE II. - Continued. MEASUREMENTS ONLY OF ICING CONDITIONS ENCOUNTERED DURING ROUTINE AIRLINE OPERATIONS FROM NOVEMBER 1951 THROUGH JUNE 1952

(b) East Coast (U.S.) routes

Pressure altitude,[a] ft	Horizontal extent of encounter, mi	Number of icing incidents for encounter	Total horizontal distance in icing, mi	Average icing rate for all icing incidents, in./hr	Average liquid-water content for all icing incidents, g/cu m	Maximum continuous icing incident within encounter: Average icing rate, in./hr	Maximum continuous icing incident within encounter: Average liquid-water content, g/cu m	Maximum continuous icing incident within encounter: Horizontal extent, mi	Calculated total ice accumulation, in.	Average true airspeed, mph
14,400	23	1	23	4.5	0.3	4.5	0.3	23	0.4	280
14,700	204	5	155	3.8	.2	4.0	.2	119	2.0	298
4,100	5	1	5	9.7	.7	9.7	.7	5	.2	262
4,200	4	1	4	12.0	.7	12.0	.7	4	.2	193
3,800	21	1	21	2.1	.1	2.1	.1	21	.2	265
17,600	150	3	60	1.5	.1	1.5	.1	40	.3	301
2,600/1,200	5	1	5	1.7	.2	1.7	.2	5	.1	156
1,700	2	1	2	3.7	.4	3.7	.4	2	.1	150
3,400/2,800	22	1	22	7.6	.5	7.6	.5	22	.9	185
6,500/3,800	39	3	32	2.7	.1	1.5	.1	5	.4	213
13,300/10,300	180	4	35	4.4	.2	2.9	.2	20	.5	300
4,400/4,000	9	1	9	2.5	.2	2.5	.2	9	.2	130
13,800	169	3	25	4.6	.4	7.2	.4	10	.4	299
13,800	260	5	107	3.4	.3	4.4	.3	56	1.3	279
4,200	4	1	4	9.0	.6	9.0	.6	4	.2	219
4,000	4	1	4	6.0	.5	6.0	.5	4	.1	225
17,300/14,400	20	1	20	6.8	.3	6.8	.3	20	.5	305
7,600/5,200	43	1	43	5.5	.3	5.5	.3	43	.9	256
13,800	38	2	24	.4	.1	1.1	.1	19	.1	283
13,800	80	4	27	.9	.1	.9	.1	13	.1	268
15,400	23	2	19	.5	.1	1.0	.1	9	.1	280
14,600	112	5	58	1.2	.1	2.5	.2	17	.3	250
21,900	131	3	74	2.1	.1	2.0	.1	63	.5	315
14,000	51	2	34	3.8	.2	4.2	.3	30	.5	255
15,700	5	1	5	6.2	.3	6.2	.3	5	.1	284
11,800/15,700	40	3	24	2.3	.2	5.5	.4	12	.2	241
19,700	46	2	26	1.4	.1	1.4	.1	21	.1	308
10,600	244	6	129	3.1	.2	1.9	.1	60	1.5	276
11,400/14,500	175	7	83	4.3	.2	2.8	.2	28	1.3	276
14,500	14	1	14	9.3	.5	9.3	.5	14	.5	282
5,000/4,700	31	1	31	5.5	.3	5.5	.3	31	.7	265
(c) Northeastern (U.S.) routes										
5,900	7	1	7	12+	0.9+	12+	0.9+	7	0.4	217
5,300	5	1	5	2.1	.1	2.1	.1	5	.1	240
5,300	71	1	71	3.7	.3	3.7	.3	71	1.3	203
4,400/2,500	97	3	48	3.3	.2	5.2	.4	21	.8	207
3,400	22	2	11	2.1	.2	1.6	.2	8	.1	167
2,500/2,000	16	1	16	6.5	.6	6.5	.6	16	.7	158
2,600/4,700	19	1	19	5.1	.5	5.1	.5	19	.6	164
4,800/1,700	103	4	79	3.3	.3	2.8	.3	35	1.6	163
1,200	6	1	6	3.0	.3	3.0	.3	6	.2	122
1,700/2,400	5	1	5	4.1	.5	4.1	.5	5	.1	159

[a] Two altitudes separated by / indicate beginning and end of icing during climb or descent.

TABLE II. - Concluded. MEASUREMENTS ONLY OF ICING CONDITIONS ENCOUNTERED DURING ROUTINE AIRLINE OPERATIONS FROM NOVEMBER 1951 THROUGH JUNE 1952

(d) Transcontinental Canada routes

Pressure altitude,[a] ft	Horizontal extent of encounter, mi	Number of icing incidents for encounter	Total horizontal distance in icing, mi	Average icing rate for all icing incidents, in./hr	Average liquid-water content for all icing incidents, g/cu m	Maximum continuous icing incident within encounter: Average icing rate, in./hr	Maximum continuous icing incident within encounter: Average liquid-water content, g/cu m	Maximum continuous icing incident within encounter: Horizontal extent, mi	Calculated total ice accumulation, in.	Average true airspeed, mph
4,800	4	1	4	12+	1.1+	12+	1.1+	4	0.2	181
2,900	3	1	3	12.0	1.1	12.0	1.1	3	.2	174
13,100	4	1	4	1.4	.1	1.4	.1	4	.1	206
13,800	5	1	5	2.5	.1	2.5	.1	5	.1	271
13,300/14,000	11	1	11	4.8	.4	4.8	.4	11	.2	227
15,600/9,100	52	3	17	2.2	.1	2.8	.2	8	.2	239
12,700	4	1	4	5.5	.5	5.5	.5	4	.1	193
13,000/4,900	24	2	22	1.8	.1	1.7	.1	14	.2	203
16,500	17	1	17	3.7	.2	3.7	.2	17	.2	249
8,300	55	2	35	7.0	.5	6.0	.5	28	1.2	208
7,400/5,200	47	3	31	4.6	.4	3.5	.3	16	.8	187
5,400/10,200	30	3	19	4.5	.4	5.0	.4	11	.4	225
7,400/4,900	19	1	19	3.9	.2	3.9	.2	19	.3	224
(e) Pacific Coast route: Seattle, Washington to Alaska										
10,700/11,800	183	4	63	2.6	0.2	2.4	0.2	25	0.8	211
13,300	39	3	32	2.5	.2	3.2	.2	14	.4	211
13,000	107	4	55	1.6	.1	1.7	.1	26	.4	221
11,000	21	1	21	2.3	.2	2.3	.2	21	.2	207
8,100	29	2	18	1.3	.1	1.1	.1	15	.1	218
8,700	55	3	17	2.9	.2	4.8	.4	7	.3	205
9,300	23	1	23	2.2	.2	2.2	.2	23	.3	193
9,700	25	1	25	1.3	.1	1.3	.1	25	.2	215
12,400	35	3	10	1.0	.1	1.0	.1	3	.1	193
9,600	147	5	93	1.8	.1	1.9	.1	79	.8	215
3,800	57	1	57	4.2	.3	4.2	.3	57	1.2	201
10,700/9,800	18	1	18	1.7	.1	1.7	.1	18	.1	212
10,500	4	1	4	7.5	.5	7.5	.5	4	.1	229
12,600	12	1	12	1.0	.1	1.0	.1	12	.1	233
9,000	13	1	13	3.6	.3	3.6	.3	13	.3	200
10,200	213	10	107	1.3	.1	1.3	.1	23	.7	200
13,000	64	2	19	4.2	.3	3.7	.3	15	.4	224
9,800	10	1	10	1.6	.1	1.6	.1	10	.1	207
9,800	4	1	4	1.7	.1	1.7	.1	4	.1	215
9,000/5,300	7	1	7	1.8	.1	1.8	.1	7	.1	212
5,900/9,200	3	1	3	1.4	.1	1.4	.1	3	.1	197
9,500	157	7	50	1.4	.1	1.2	.1	13	.4	201
9,600	11	1	11	1.0	.1	1.0	.1	11	.1	219
10,500	51	3	20	2.6	.2	3.1	.2	7	.3	204
10,500	74	2	17	3.7	.3	3.4	.3	10	.3	202
9,600	7	1	7	2.1	.2	2.1	.2	7	.1	197
9,600	48	2	44	2.3	.2	2.5	.2	31	.5	204
9,600	21	1	21	2.0	.2	2.0	.2	21	.2	212

[a]Two altitudes separated by / indicate beginning and end of icing during climb or descent.

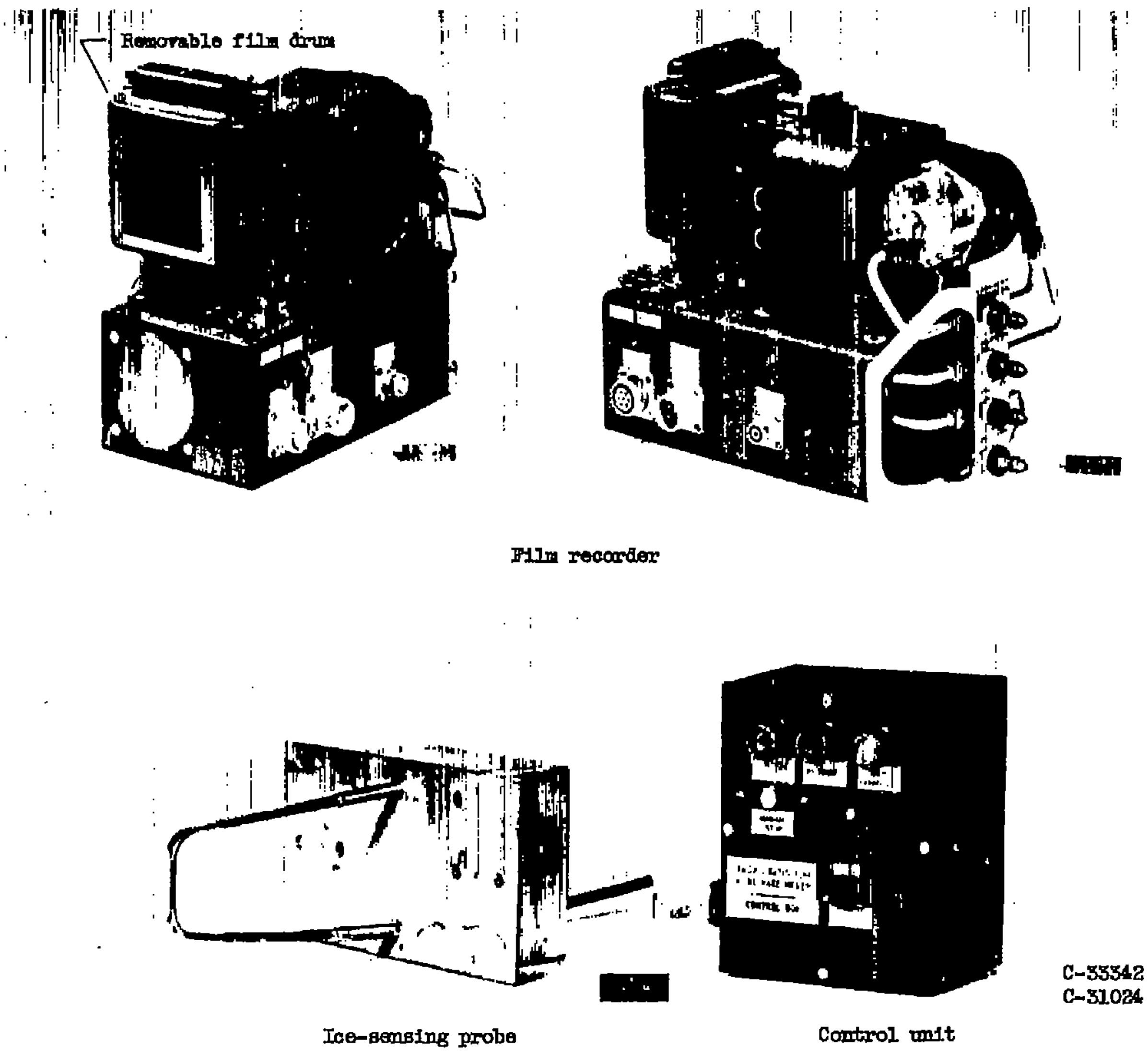

Figure 1. - Components of NACA pressure-type icing-rate meter.

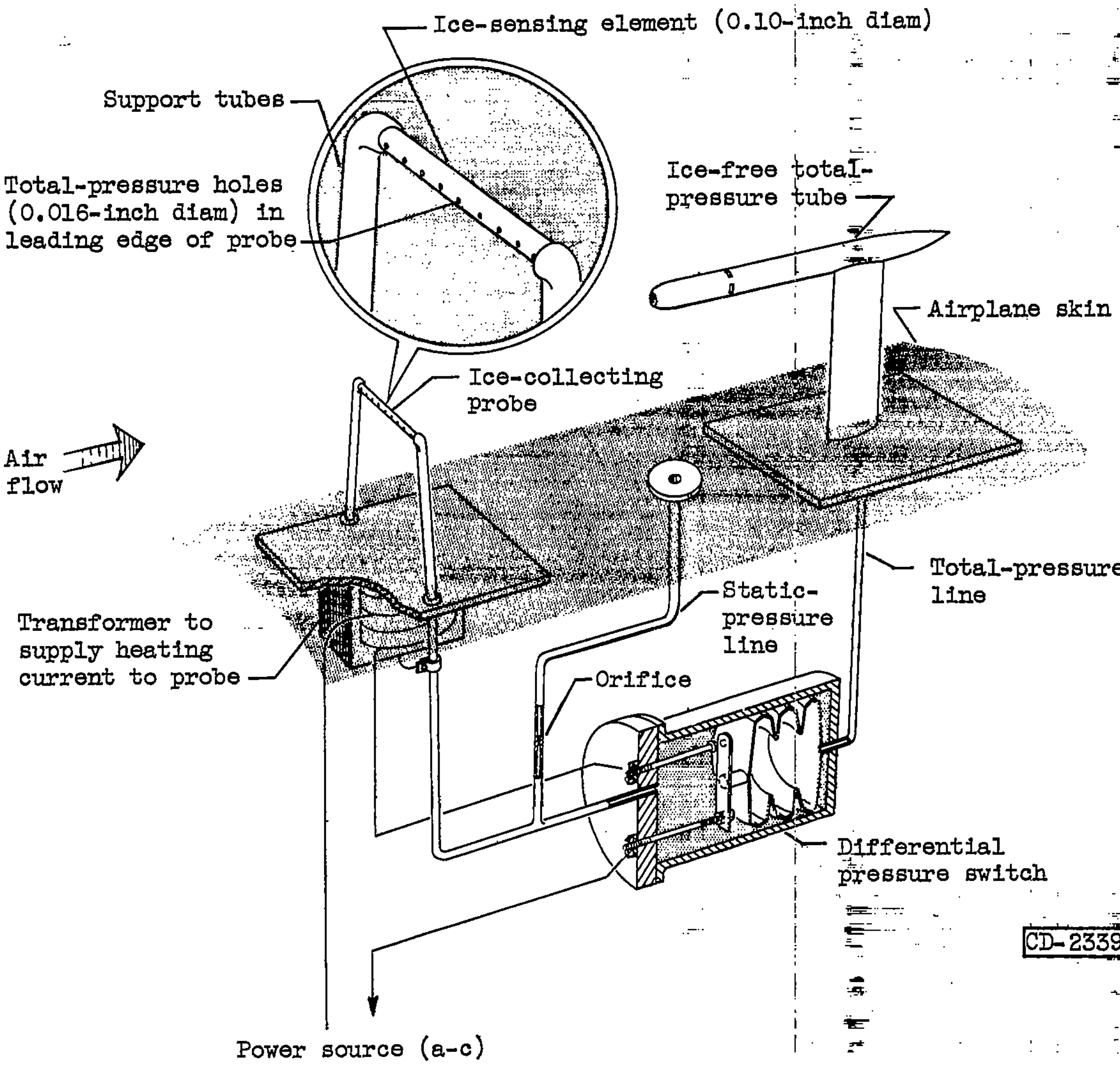

Figure 2. - Schematic diagram of NACA pressure-type icing-rate meter.

3017

CA-3 back

NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS
Lewis Flight Propulsion Laboratory

21000 Brookpark Rd.
Cleveland 11, Ohio

Recorder Counter No. at Installation: ______	Data Sheet No. 798
	Film Drum No. ______
	Airline ______
at Removal: ______	Icing Meter No. ______
	Airplane No. ______

ICING DATA SHEET FOR STATISTICAL STUDY OF AIRCRAFT ICING

Please Note. These data supplement measurements of rate of icing being recorded on film by NACA icing rate meter installed on this aircraft. Meter automatically starts upon encountering icing (recording light) and stops approximately 15 minutes after end of an icing encounter (flashing light). Numerical recorder counter identifies icing encounters on recorder film and therefore must be entered on this sheet to correlate these data with the film records.

Fill in following information when icing is encountered:
(Space on back for any detailed comments such as operation of meter, type of ice, cloud formations, effects on aircraft, etc.)

REC-ORDER COUNT-ER NO.	DATE	FLIGHT NO.	TIME AT START OF ICING (LOCAL)	EST'D TIME IN ICING (MIN)	ALT. MSL (FEET)	OUTSIDE AIR TEMP. °F OR °C	EST'D ICING INTEN-SITY	DE-ICING EQUIP. USED?	GEOGRAPHIC LOCATION OF ICING
									c. 818 (6/9/52)

Figure 3. - Sample of data sheets supplied with each icing-rate meter film drum to obtain supplemental icing information from flight crews.

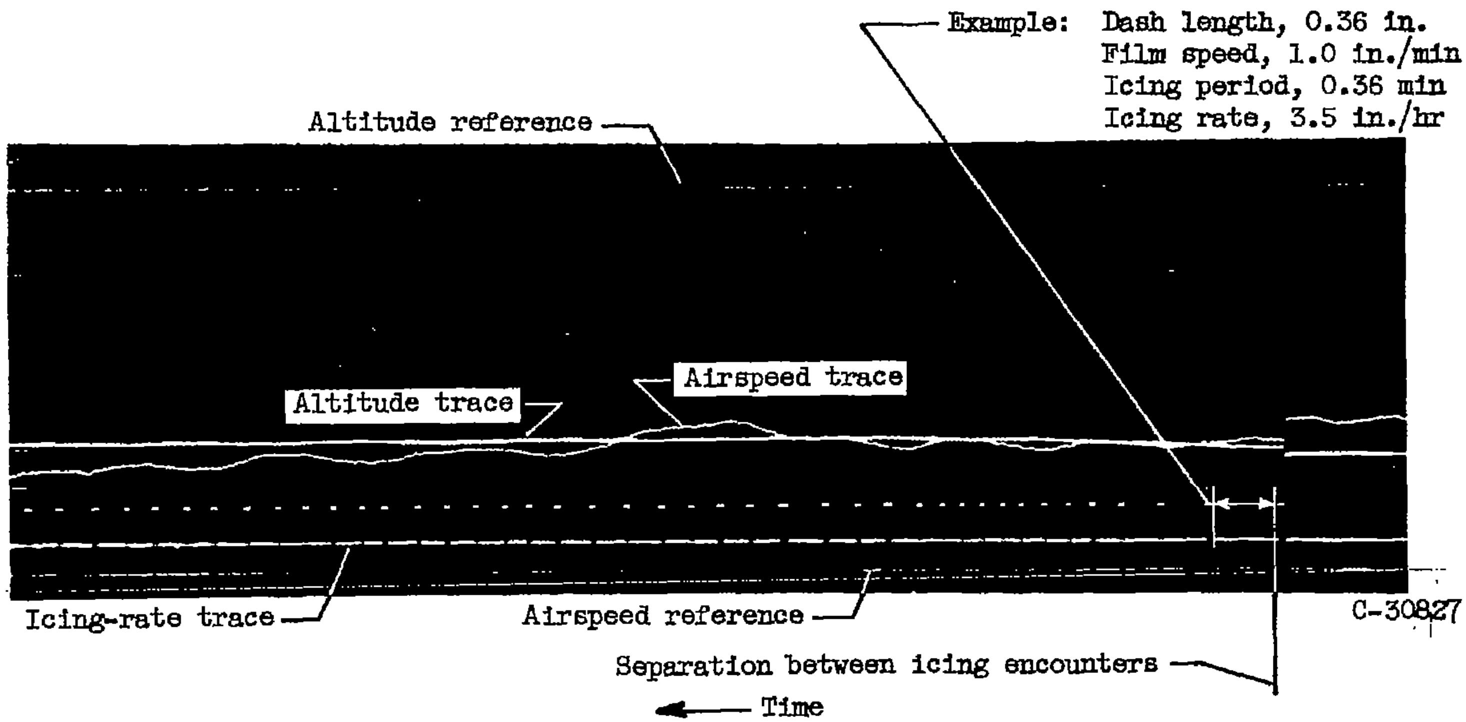

Figure 4. - Section of data film from pressure-type icing-rate meter recorded during icing encounter by airline aircraft.

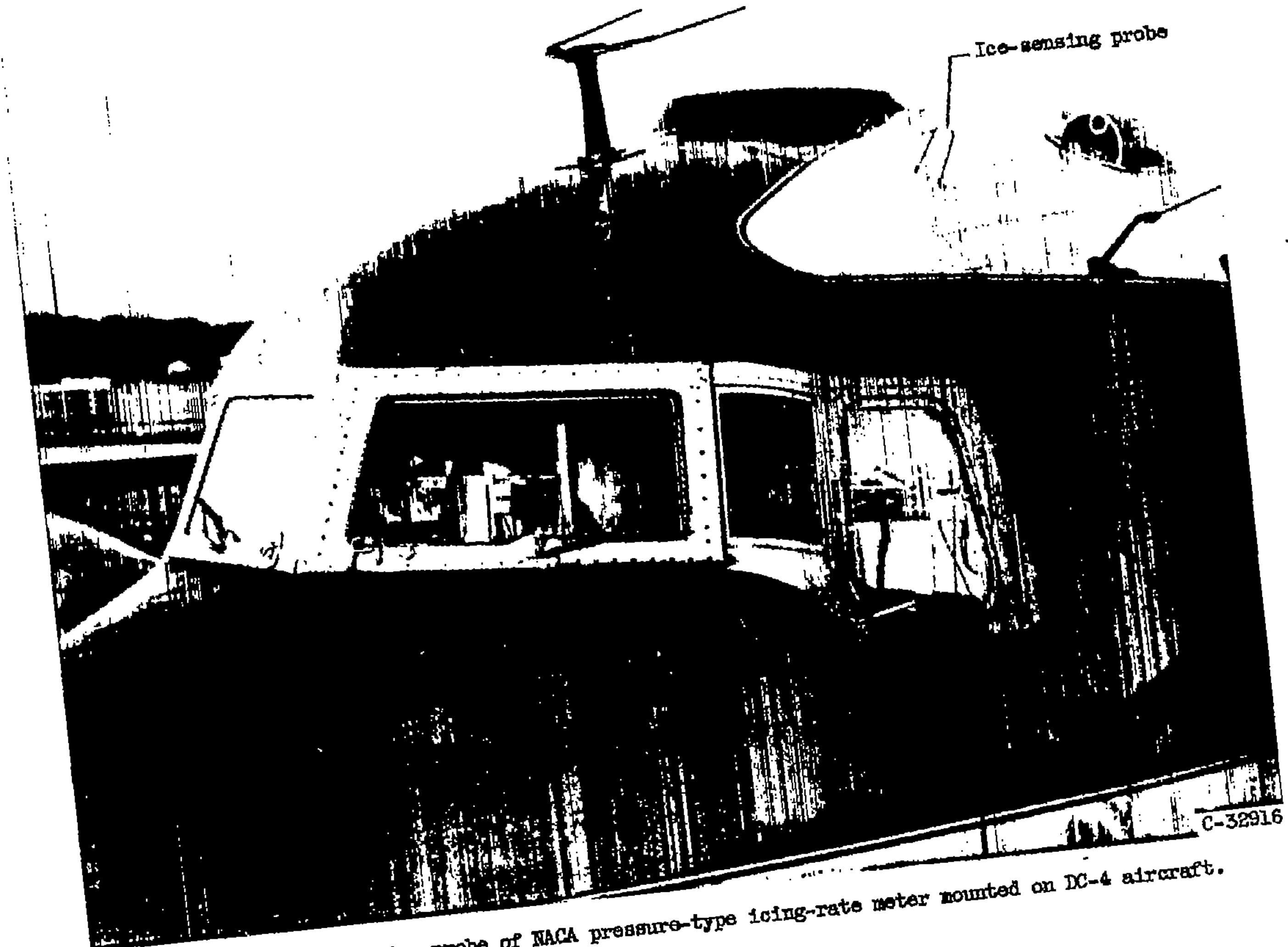

Figure 5. - Ice-sensing probe of NACA pressure-type icing-rate meter mounted on DC-4 aircraft.

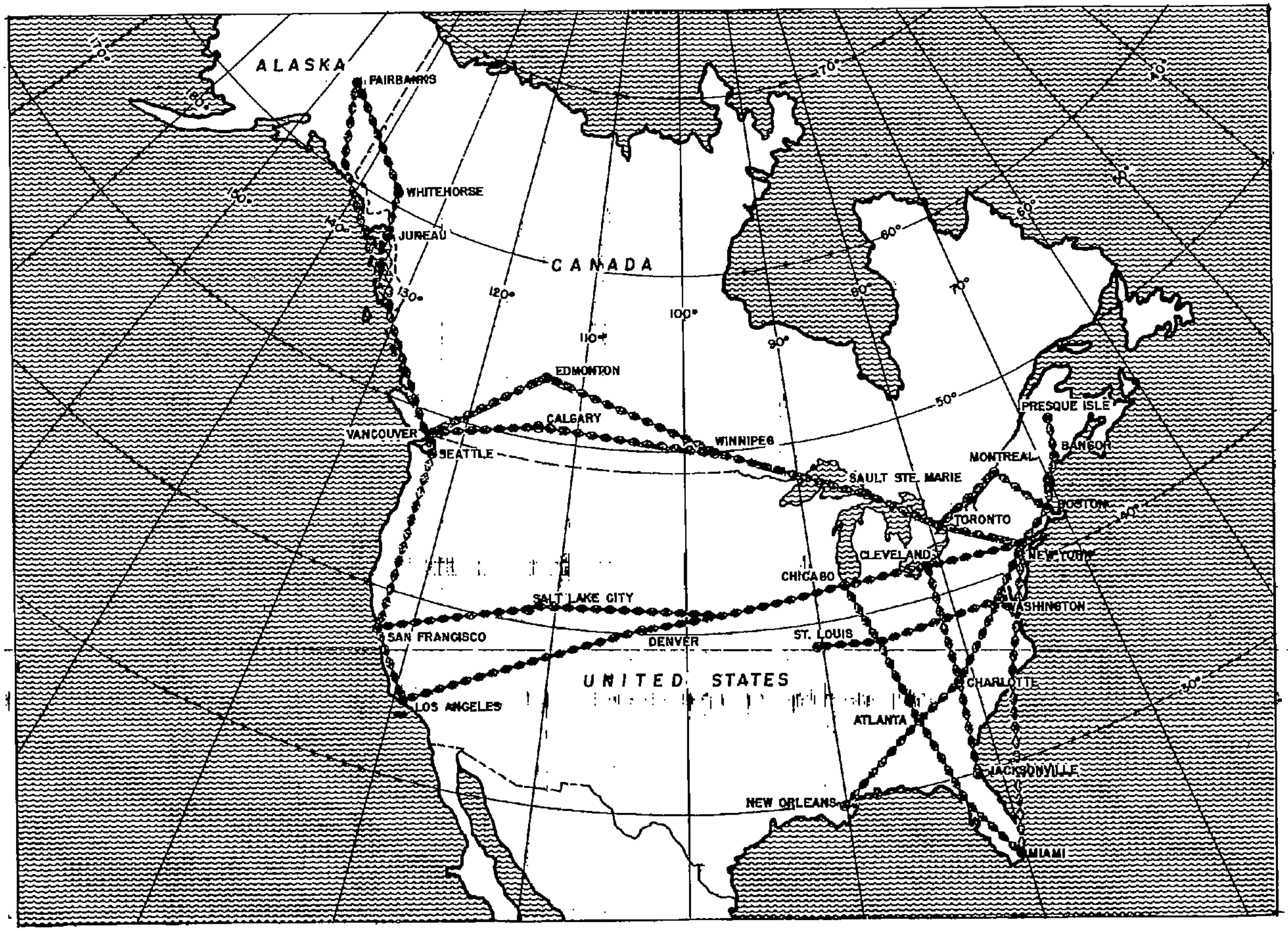

Figure 6. - Air routes covered by the five airlines collecting icing data during 1951 and 1952.

CD-4566

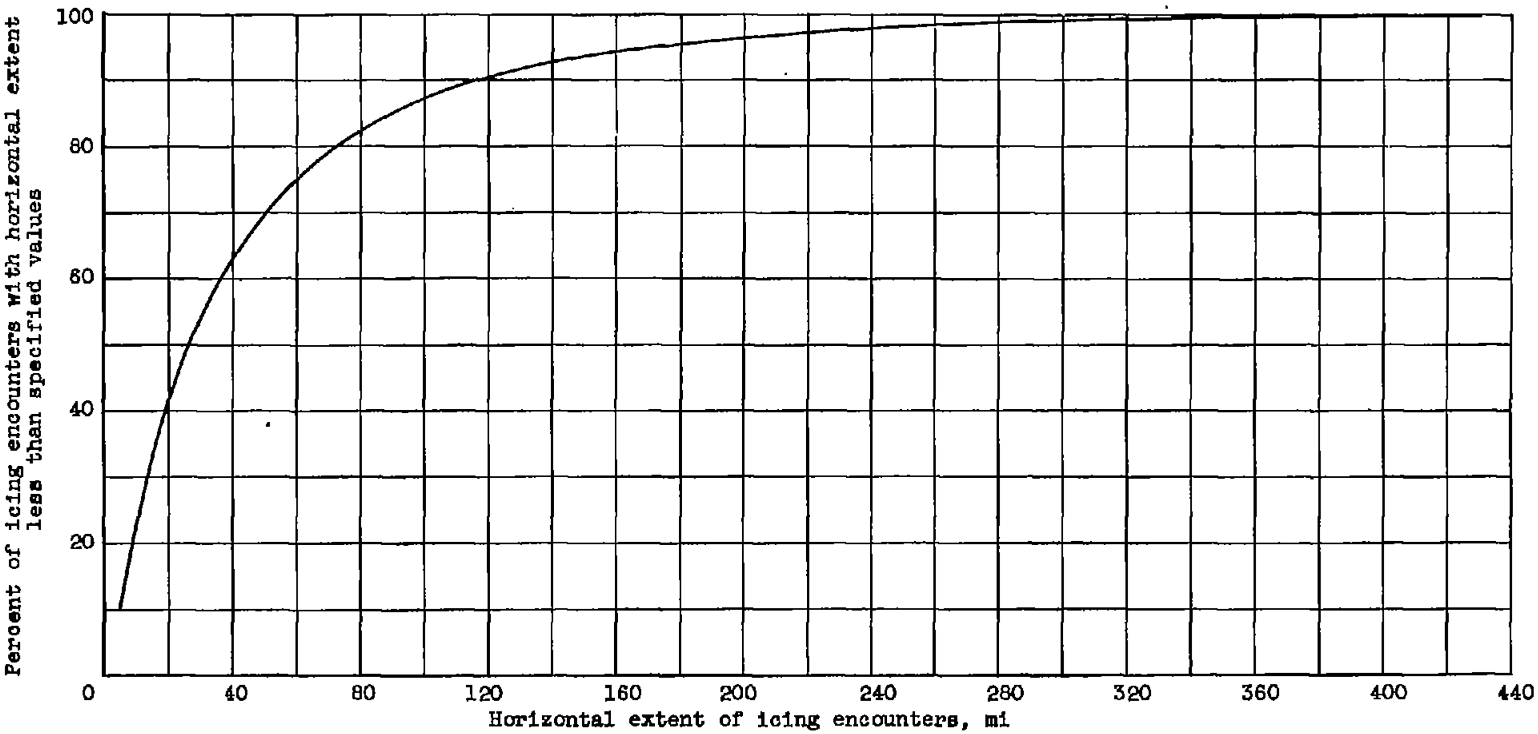

Figure 7. - Cumulative frequency of horizontal extent of icing encounters.

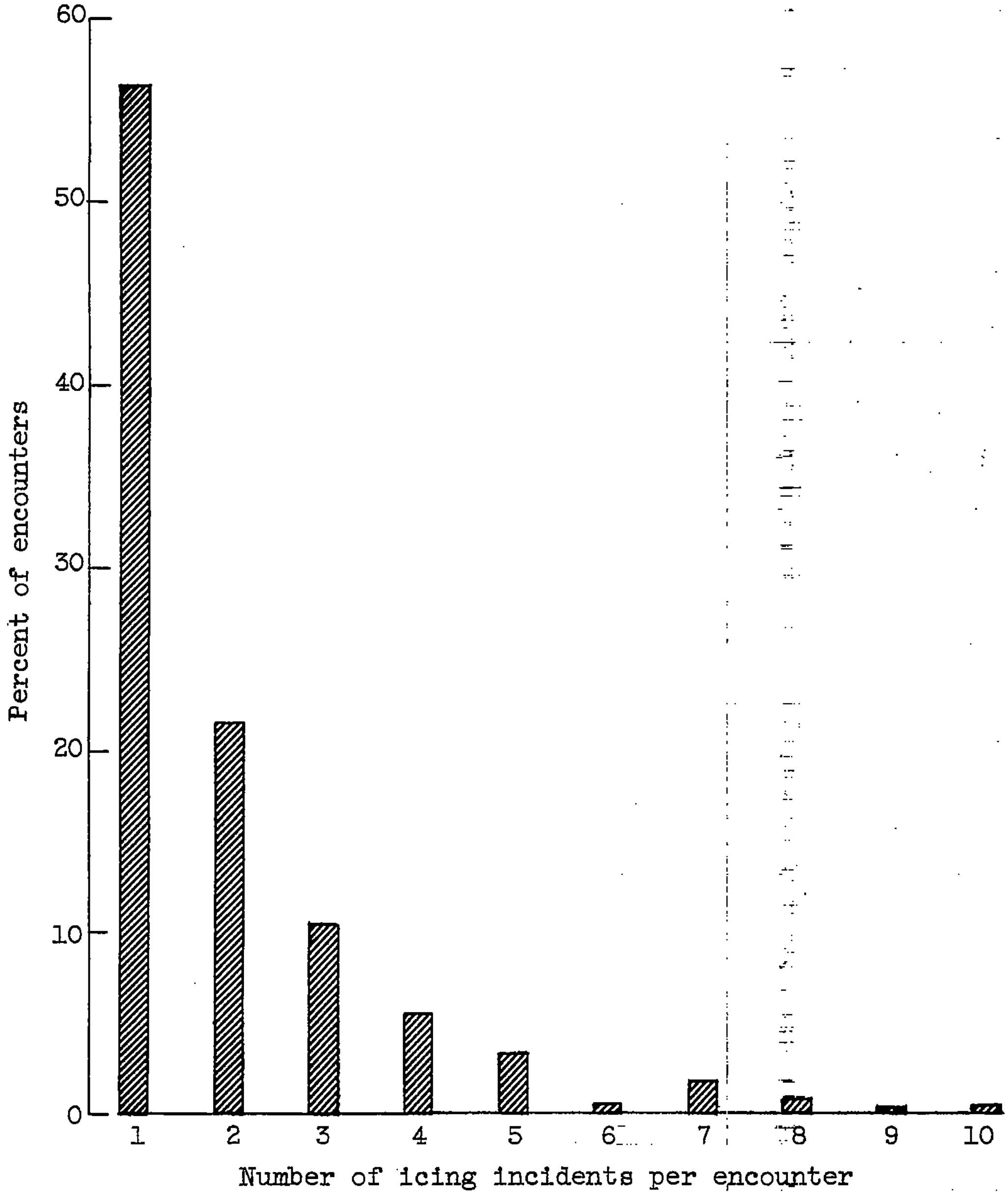

Figure 8. - Frequency distribution of icing incidents per encounter.

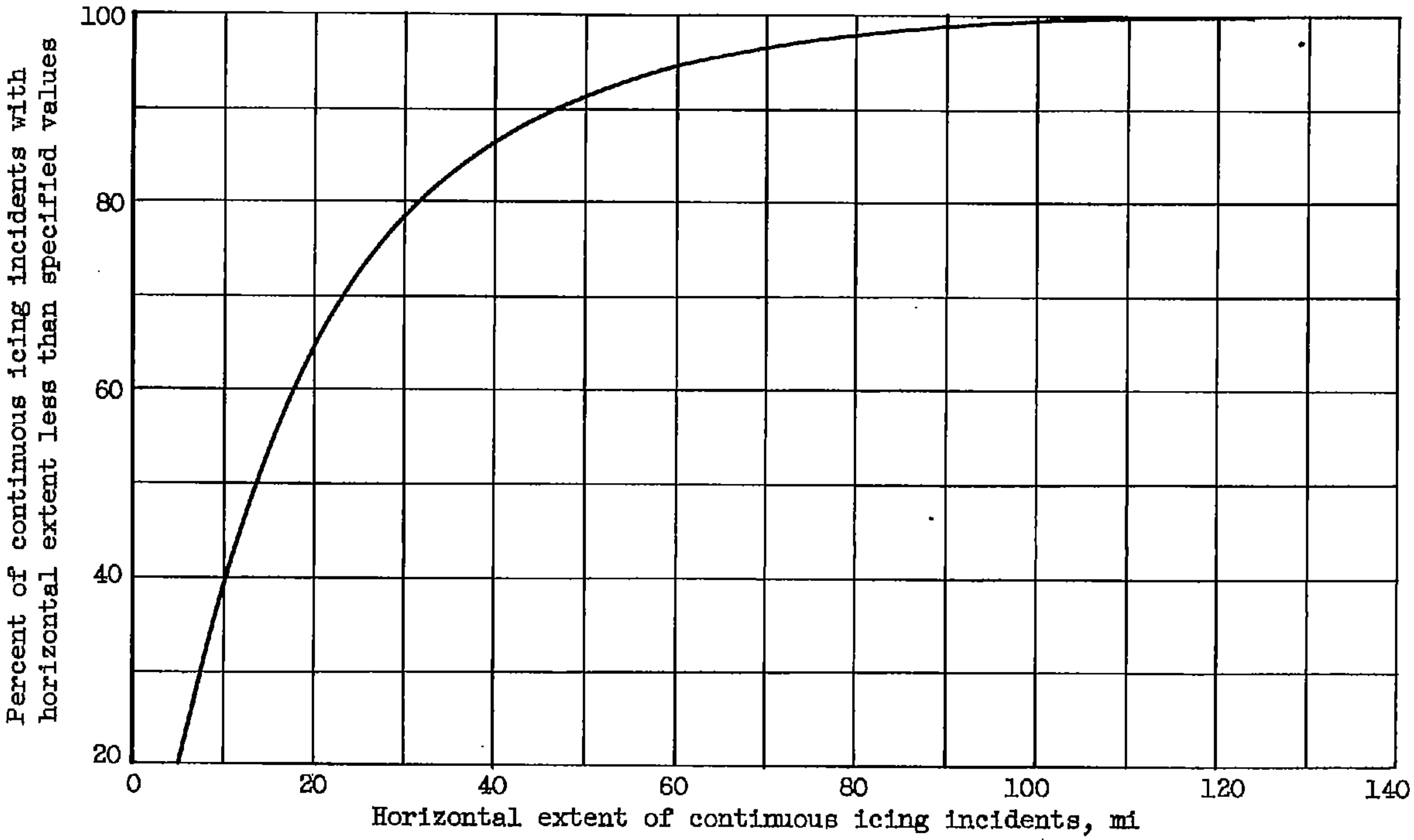

Figure 9. - Cumulative frequency of horizontal extent of continuous icing incidents within icing encounters.

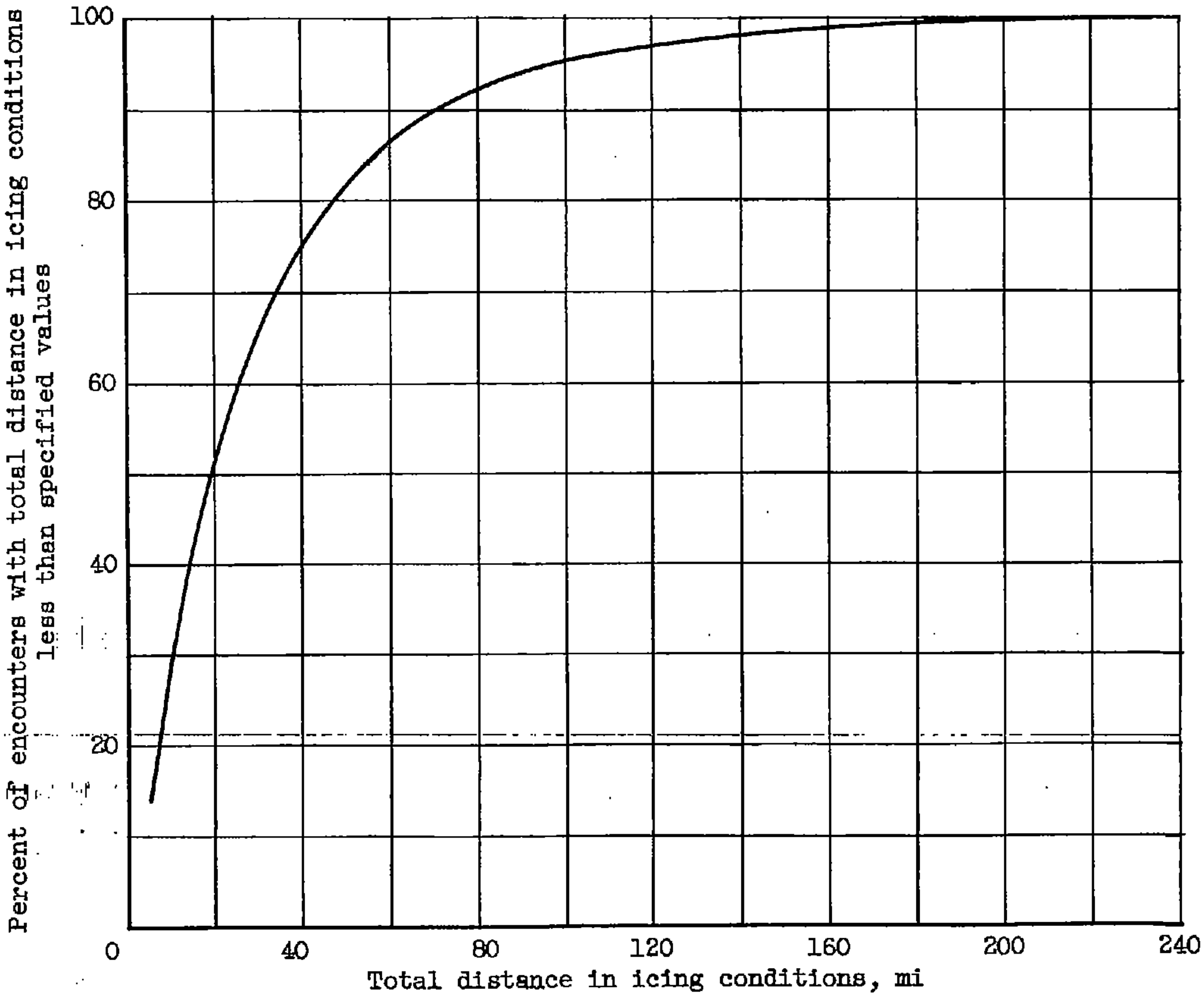

Figure 10. - Cumulative frequency of total distance in icing conditions obtained by summation of all icing incidents within the encounters.

3017

CA-4 back

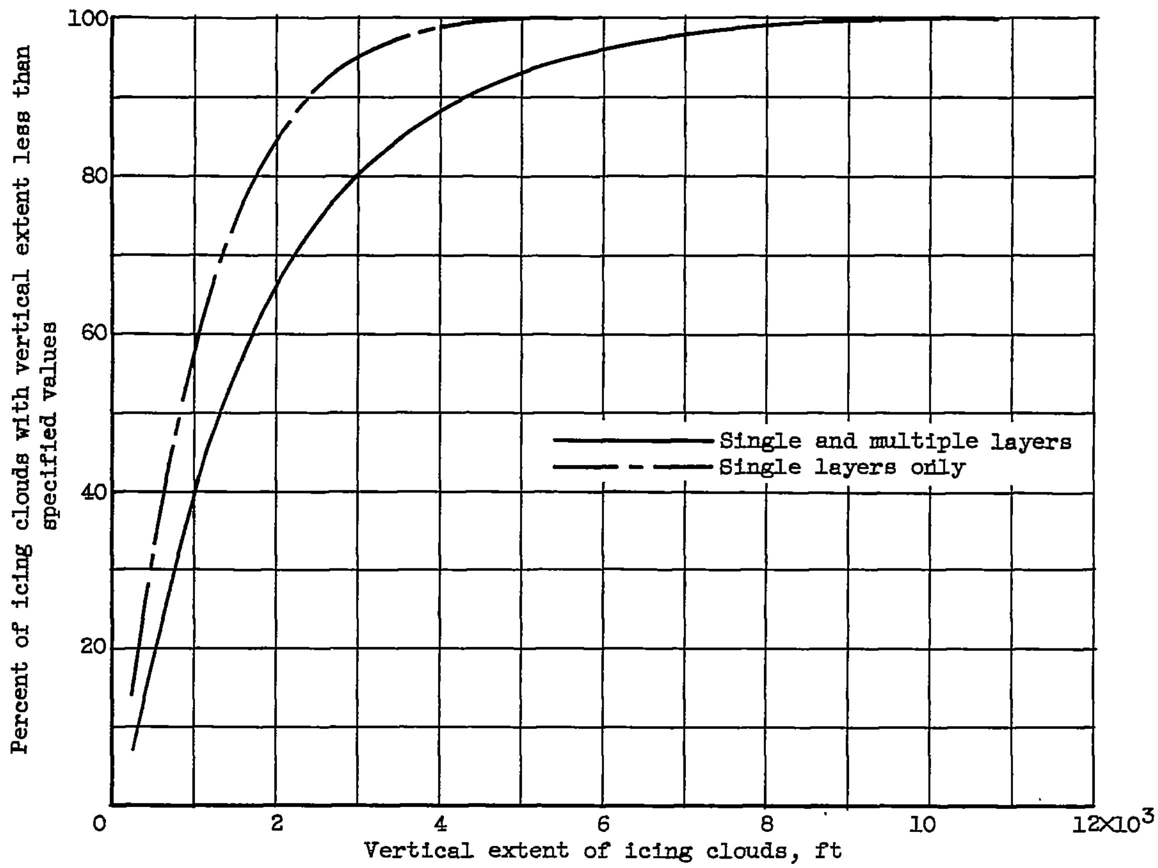

Figure 11. - Cumulative frequency of vertical extent of icing clouds obtained during routine climbing and descending.

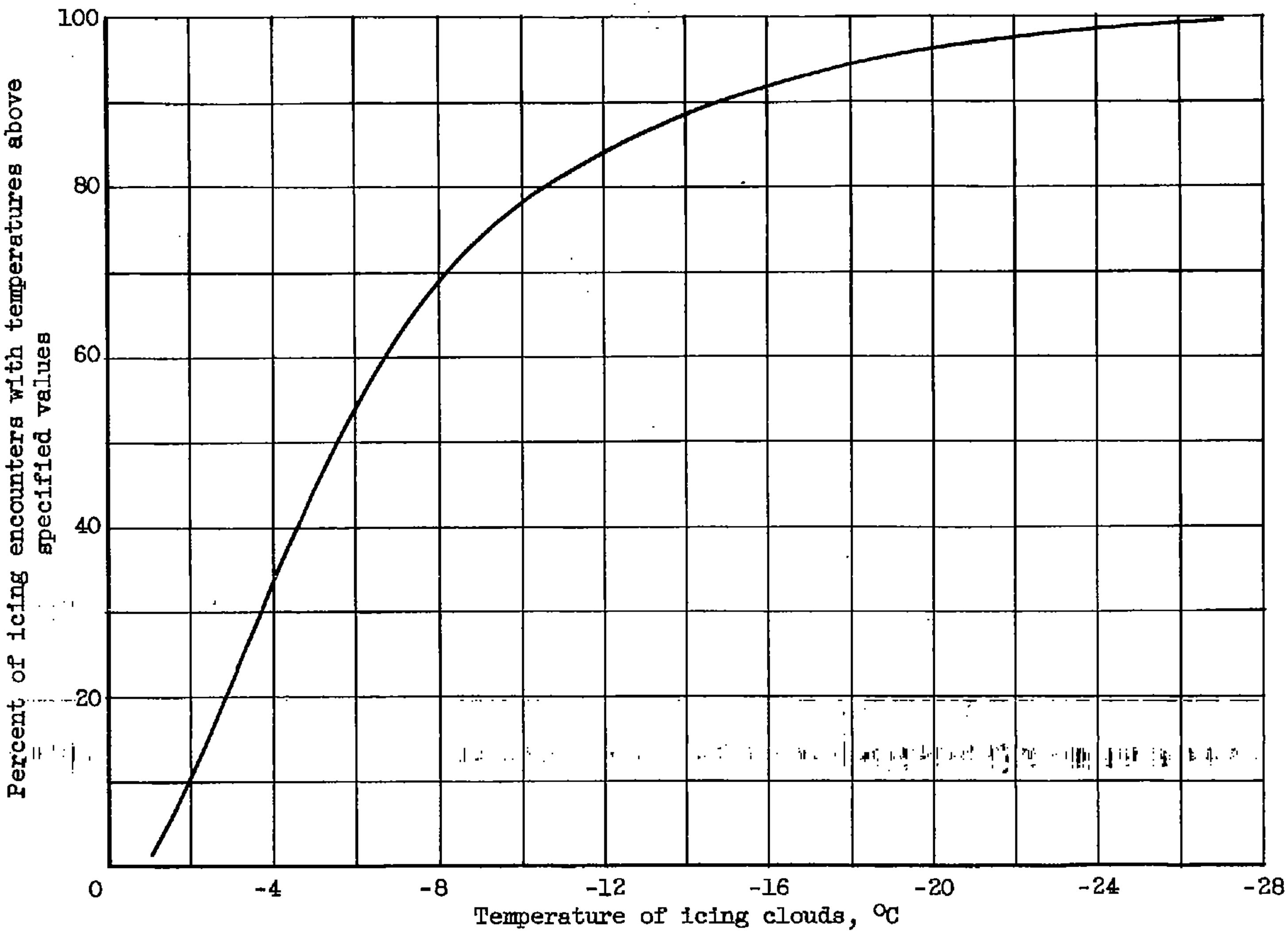

Figure 12. - Cumulative frequency of temperature of icing clouds.

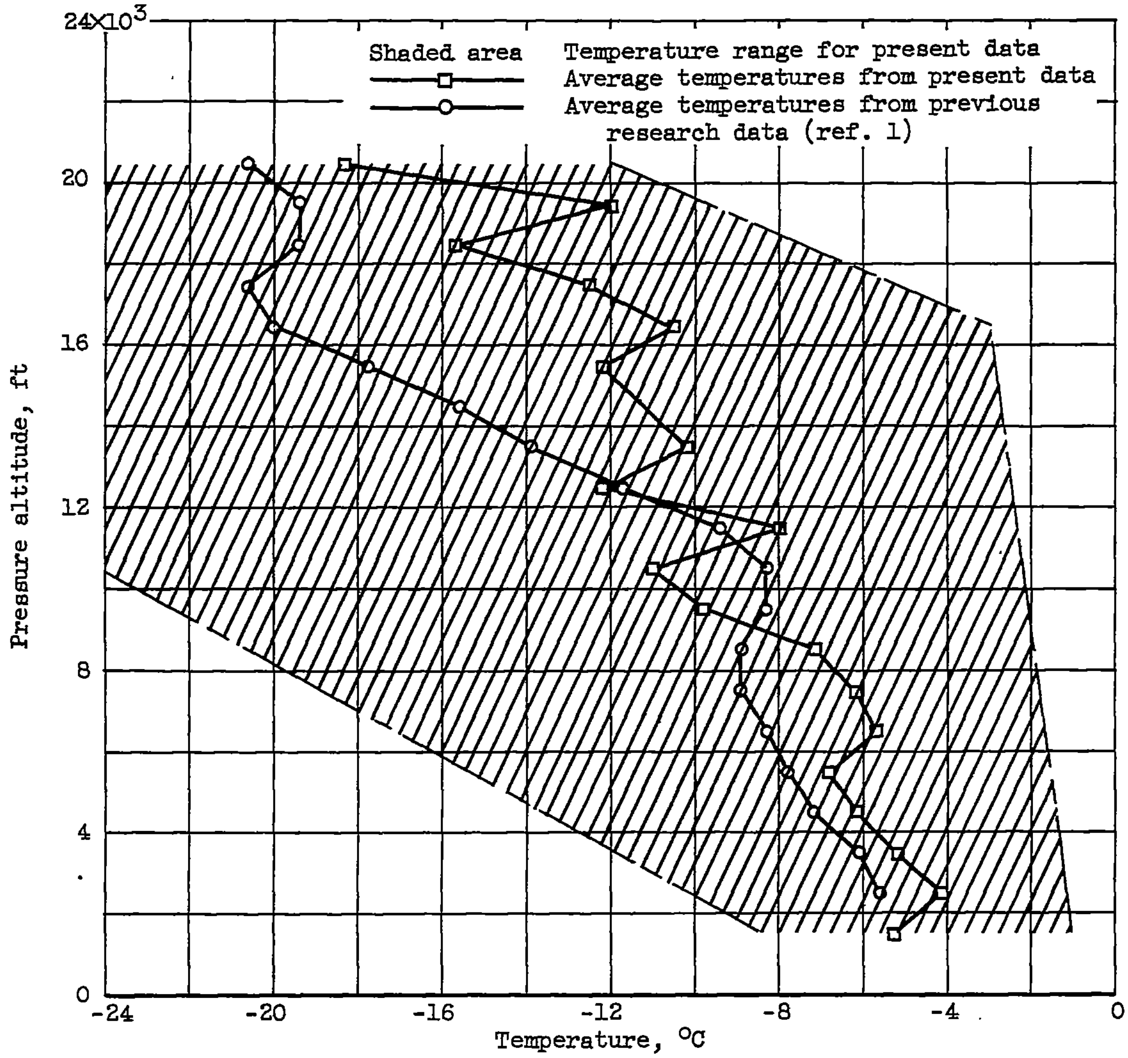

Figure 13. - Variation of icing cloud temperatures with pressure altitude.

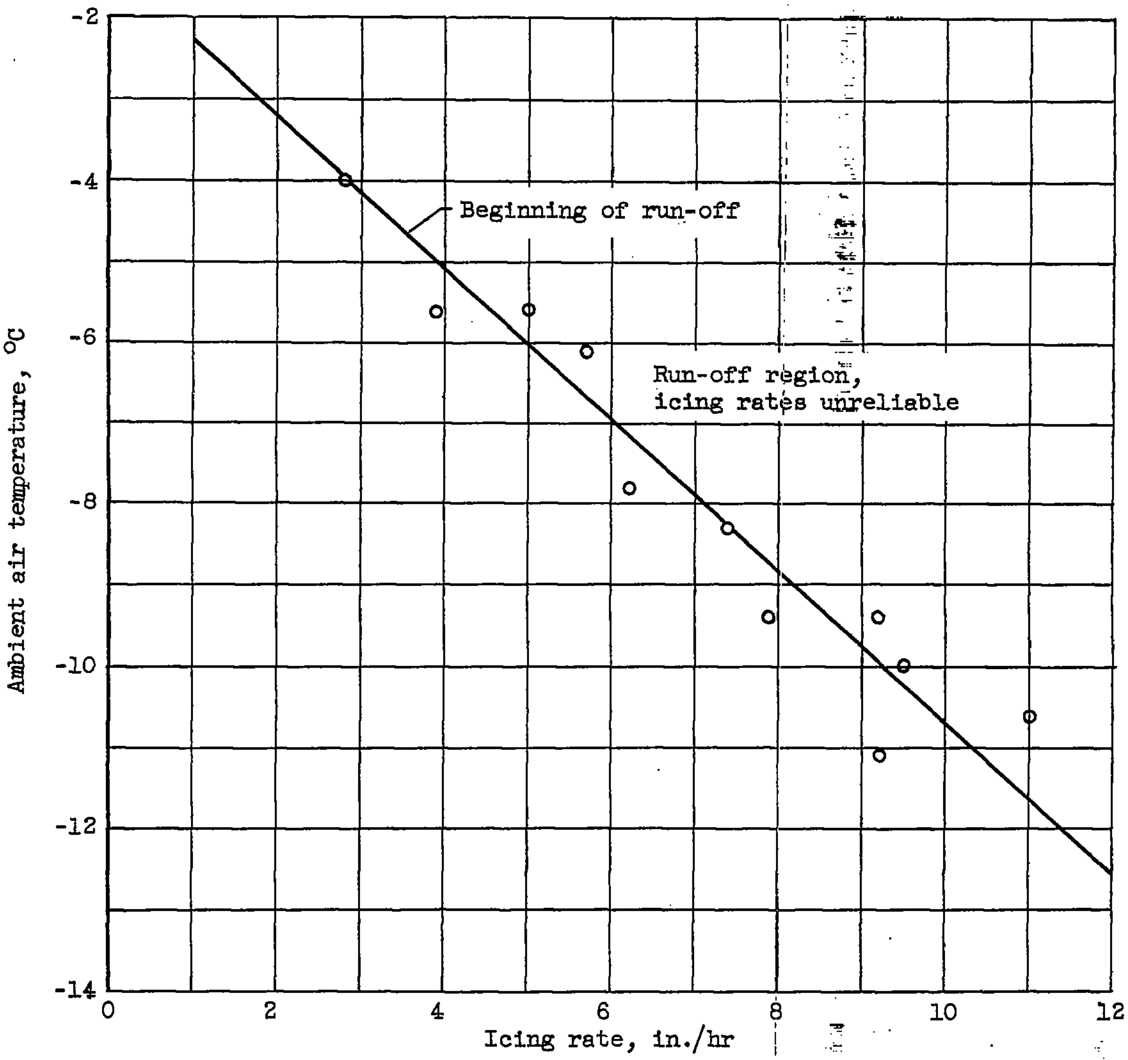

Figure 14. - Incomplete freezing (run-off limit) as a function of icing rate and air temperature on sensing probe of icing-rate meter. Observed data, 150 to 250 mph.

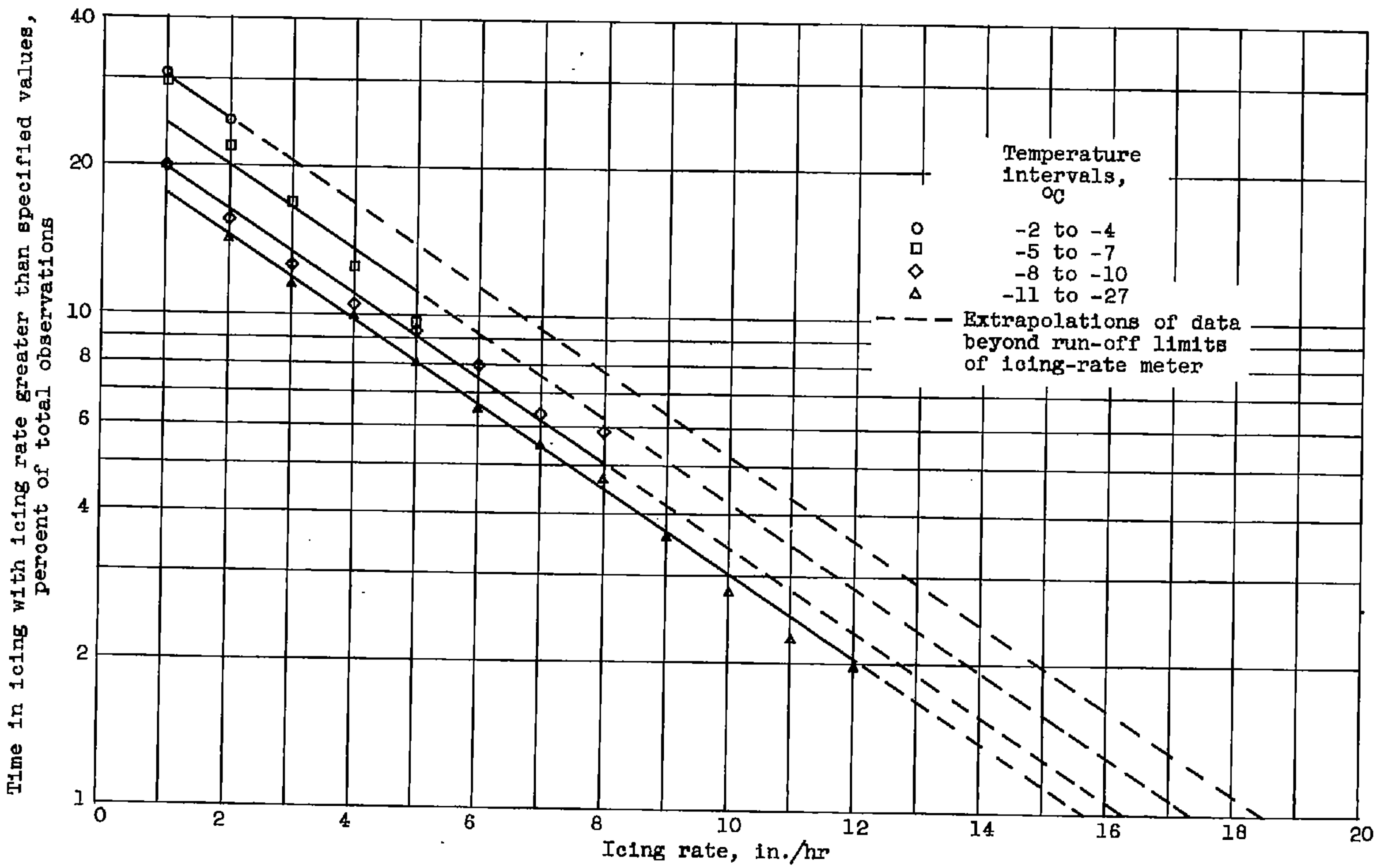

Figure 15. - Cumulative frequency of icing rate at various temperature intervals.

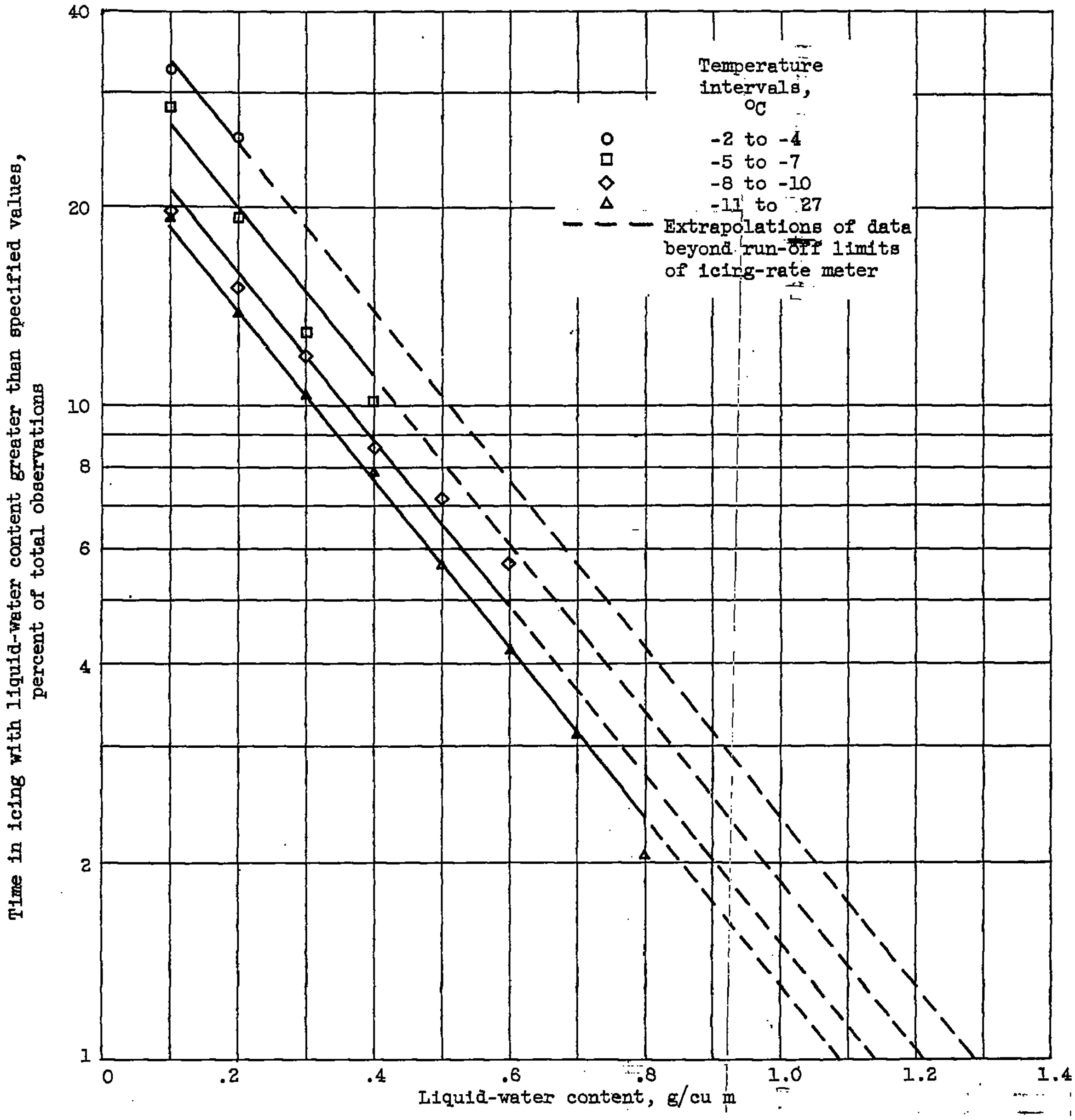

Figure 16. - Cumulative frequency of liquid-water content at various temperature intervals computed from icing-rate data.

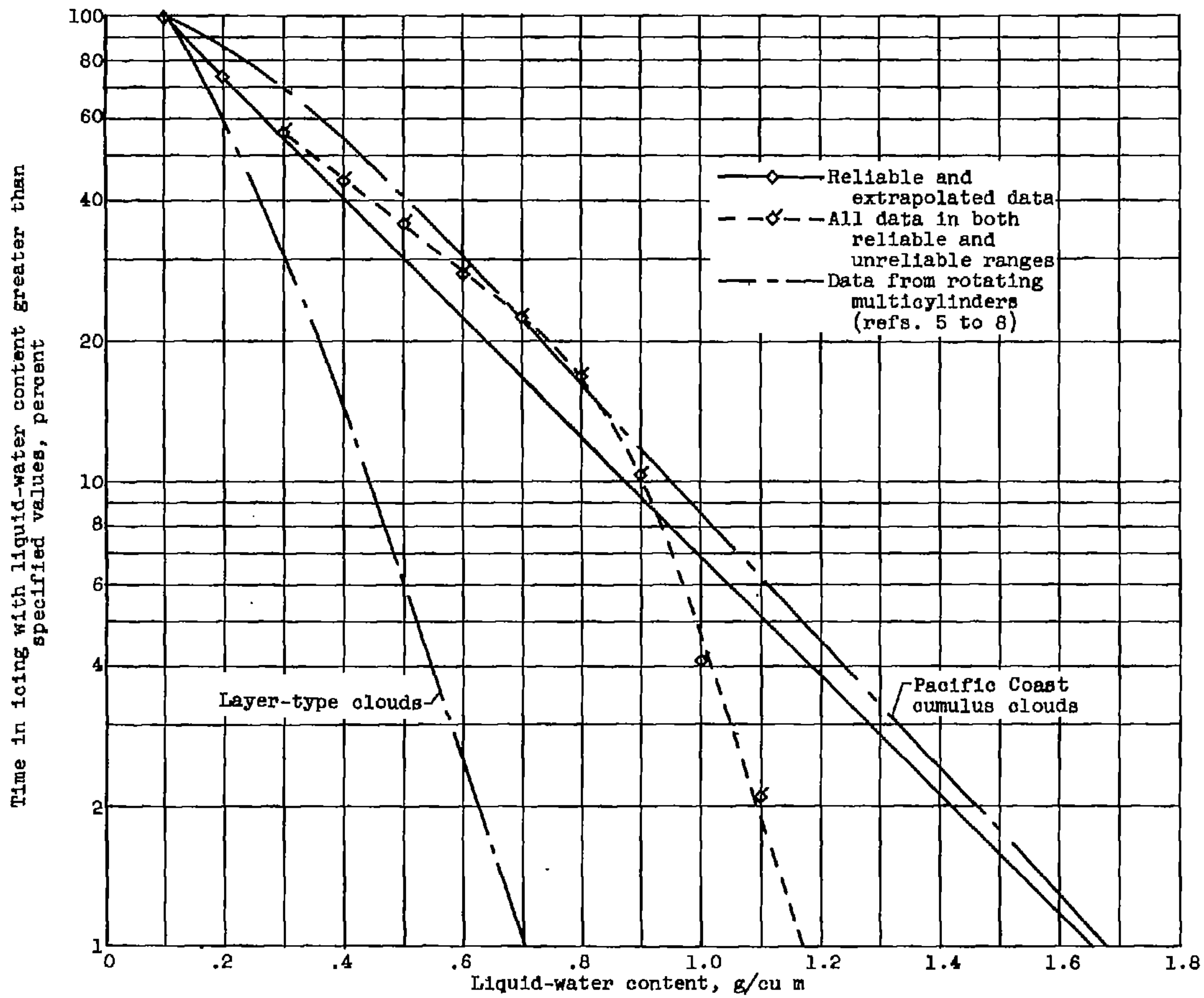

Figure 17. - Cumulative frequency of all liquid-water content data.

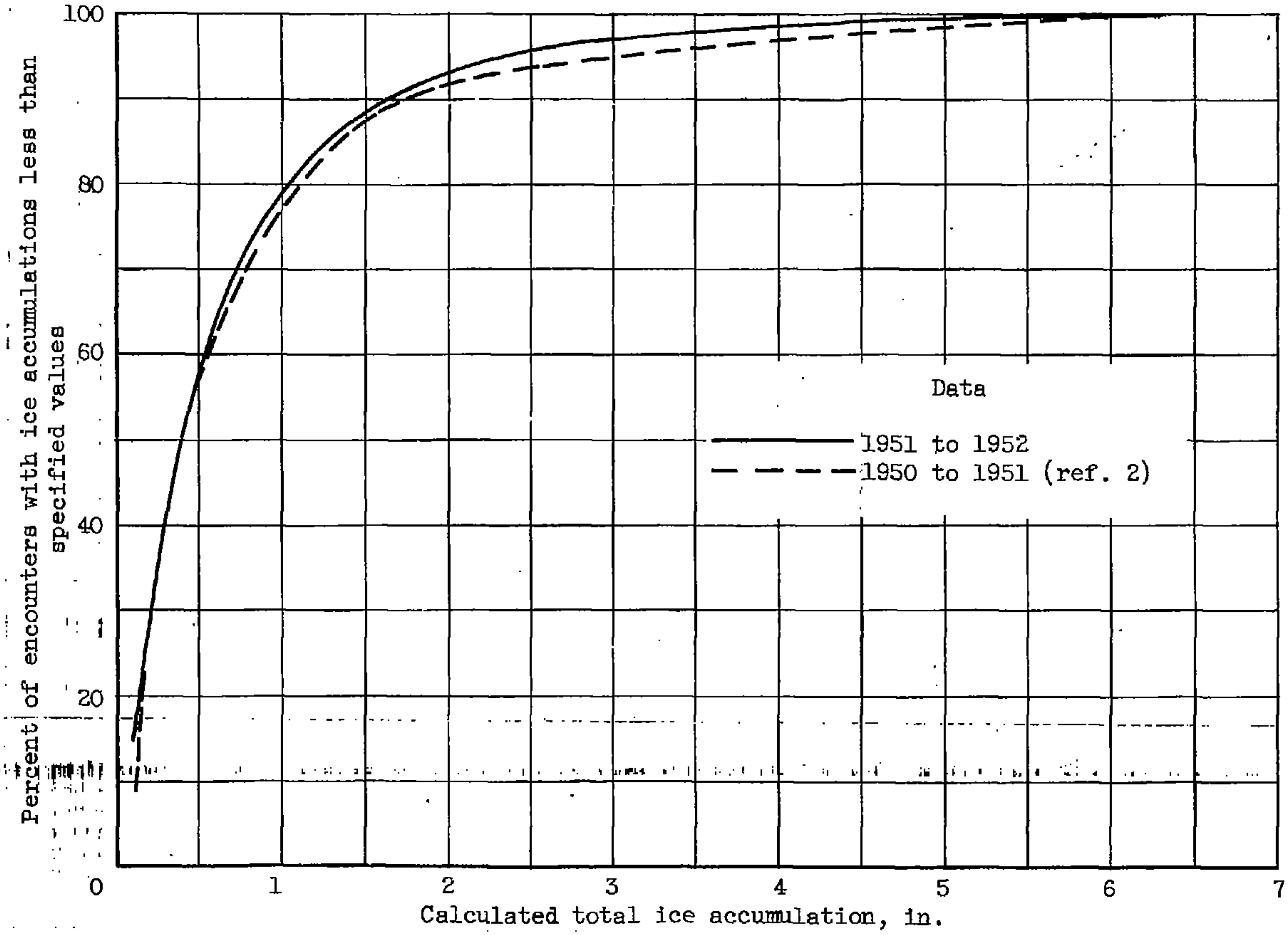

Figure 18. - Cumulative frequency of calculated total ice accumulation on sensing probe of icing-rate meter.

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